Controlling Nanostructures in Organic Photovoltaic Cells

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Organic photovoltaics (OPVs) is a promising alternative to inorganic solar cells as green energy sources and offer the advantage of low cost, easy fabrication, and compatibility with flexible substrates over a large area. However, the low dielectric constant and low carrier mobility in organic semiconductors result in strong exciton binding energy and the short exciton diffusion length, which limit the power conversion efficiency of OPVs.

The ideal OPV structure to address the above limitation is one that can produce controlled nanoscale morphology between an electron donor and acceptor material, and having the donor-acceptor interface vertically oriented to the cathode and the anode, where the excitons can be fully dissociated to electrons and holes, and can be efficiently transported to the electrodes before recombination. We will describe our effort toward this goal. Figure 1 shows sub-20 nm scale organic semiconductor nanopillars fabricated by advance lithography based on block copolymer nanotemplate and nanoimprint lithography (NIL). Key challenges in achieving the ideal OPV structures and several solutions will be discussed.

Alternatively, the bulk heterojunction (BHJ) structure can produce interpenetrating nanoscale networks of electron-donor and acceptor with domain sizes approaching the exciton diffusion length. BHJ is one of the most successful structures giving the highest efficiencies for polymer PV cells. The nano domain formation is a result of the phase separation between the donor and acceptor, which can also cause non-uniform distribution of the two components in the vertical direction, and impact the charge transport and device performance. Moreover, the commonly used annealing processes require relatively long processing time (*e.g.* tens of minutes for thermal annealing and a few hours for solvent annealing); and spin-casting deposition can only be applied to small and rigid substrate. Both aspects present serious limitation to practical large area and mass production of polymer solar cells. To address these issues, we introduce a new fabrication process (termed ESSENCIAL) utilizing a gas-permeable cover layer for solvent evaporation that protect the otherwise free surface, and simultaneously induce sheer flow of the blend solution by an applied pressure. The process leads to optimized morphology with more uniform distribution and crystallinity of the components favorable for charge generation and transport that cannot be achieved by conventional thermal and solvent annealing methods. Furthermore the ESSENCIAL technique can be extended to the fabrication of bilayer polymer PVs, which significantly facilitates interdiffusion between the donor and acceptor layers inducing optimized morphology favorable for charge generation and transportation that cannot be achieved by the conventional BHJ structure. Significant increase in short circuit current has been observed.

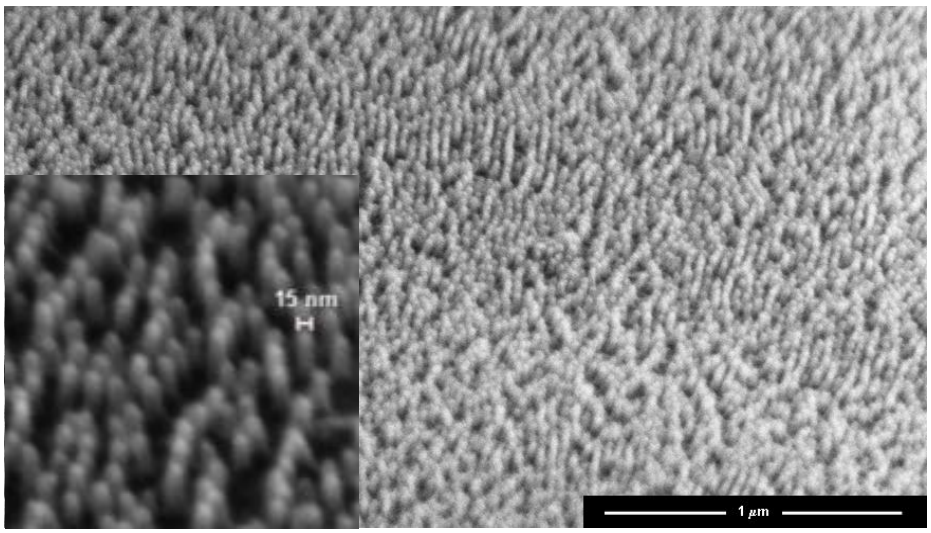
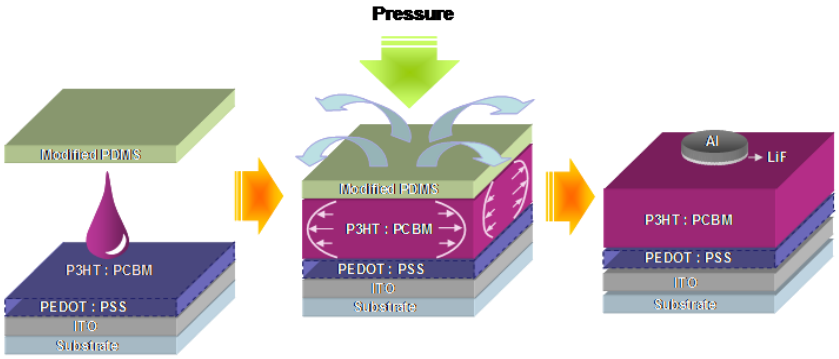


Figure 1. High aspect ratio sub-20nm P3HT nanopillar structure fabricated by advanced lithography based on block copolymer nanotemplate and NIL.

(a)



(b)

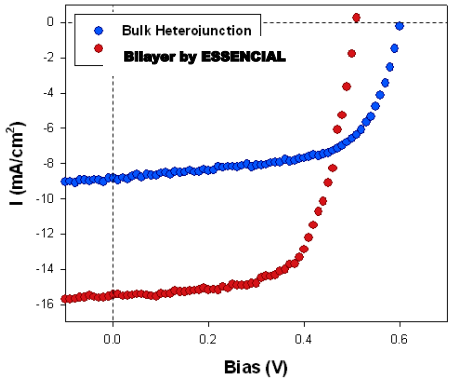


Figure 2. (a) Schematic of the ESSENCIAL process to produce optimized nanoscale domains in BHT OPVs. (b) Comparison of J-V curves for thermally annealed BHJ device and the bilayer OPV device fabricated by the ESSENCIAL process.