Reducing Optical Losses In Organic Photovoltaic Devices Using Microlens Arrays: Theoretical And Experimental Investigation

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ABSTRACT

Over the last decade, organic photovoltaic (OPV) devices have attracted a lot of attention and highest power conversion efficiencies (PCE) are now close to 10%. However, the performance is still much lower than that in the inorganic photovoltaic devices, like the widely commercialized silicon solar cells. There are many losses that can be contributed to the low efficiencies of OPV devices. Among them, optical loss is a big part, which can account for ~40% of total losses. The incident solar spectrum still largely remains poorly absorbed. In the OPV device structure, the thicknesses (~ 100-200 nm, at times less) are not enough to efficiently absorb light, and thicknesses cannot be indiscriminately increased further because of low charge carrier mobilities in most organic materials. Hence, to boost efficiencies further, it is imperative to improve light absorption within existing PSC architectures.

Here an optical structure - microlens array (MLA) - was employed to increase light absorption inside the active layer, and PCE of OPV devices increased even for optimized devices. Normal incident light rays are refracted at the MLA and travel longer optical paths inside the active layers. Three OPV systems - poly(3-hexylthiophene-2,5-diyl):(6,6)-phenyl C61 butyric acid methyl ester (P3HT:PCBM), poly[[9-(1-octylnonyl)-9H-carbazole-2,7-diyl]-2,5-thiophenediyl-2,1,3-benzothiadiazole-4,7-diyl-2,5-thiophenediyl]:(6,6)-phenyl C71 butyric acid methyl ester (PCDTBT:PC_{71}BM), and 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)):(6,6)-phenyl C71-butyric acid methyl ester (PTB7:PC_{71}BM) were investigated. In the P3HT:PCBM system, MLA increased the absorption, absolute external quantum efficiency , and the PCE of an optimized device by ~ 4.3%. In the PCDTBT:PC_{71}BM system, MLA increased the absorption, absolute external quantum efficiency, and PCE by more than 10%. After optimizing the dimension of MLA, we observed up to 17% enhancement in the short circuit current of PCDTBT:PC_{71}BM cells, and 10% enhancement in the short circuit current of

$PTB7{:}PC_{71}BM$ cells. In addition, simulations incorporating optical parameters of all structural layers were performed and they support the enhancement of absorption in the active layer with the assistance of MLA. Theoretically and experimentally investigating several MLA dimensions, we found that photocurrent increases with the ratio of height to pitch size of MLA. Simulations reveal the enhancement mechanisms: MLA focuses light, and also increases the light path within the active-layer by diffraction. The results show that utilizing MLA is an effective strategy to further increase light absorption in OPV devices. Moreover, the MLA is on the substrate side opposite to the active layer and does not hinder the cell fabrication or electrical characteristics. It is also generally applicable to all types of solar cells due to its non-intrusive and external nature.