

DOCTORAL THESIS

Broadband light absorption enhancement in organic solar cells

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Abstract

The aim of this thesis was to undertake a comprehensive research to study the broadband light absorption enhancement in organic solar cells (OSCs) with different nano-structures, thereby improving short-circuit current density and efficiency. Absorption enhancement in OSCs having different photonic structures, compared to the control planar cell configuration, was analyzed and studied using the optical admittance analysis and finite-difference time-domain (FDTD) method. After a brief overview of the latest progresses made in OSCs, the basic optical principles of light scattering, surface plasmon polaritons (SPPs), localized surface plasmon resonance (LSPR), diffraction effect and waveguide mode, that had been employed for light trapping in OSCs, are discussed.

Optical admittance analysis reveals that light absorption in inverted OSCs, based on polymer blend layer of P3HT:PCBM, is always greater than the conventional geometry OSCs fabricated using an ITO/PEDOT:PSS anode. The inverted bulk heterojunction OSCs, made with a pair of an ultrathin Al-modified ITO front cathode and a bi-layer MoO₃/Ag anode, exhibited a superior power conversion efficiency (PCE) of 4.16%, which is about 13% more efficient than a control normal OSC. It is shown that the reverse configuration allows improving charge collection at cathode/blend interface and also possessing a dawdling degradation behavior as compared to a control regular OSC in the accelerated aging test.

Light absorption enhancement in ZnPc:C₆₀-based OSCs, made with substrates having different structures, for example, surface-modified Ag nanoparticles and 1-D photonic structures, was analyzed. The effect of an ultra-thin plasma-polymerized fluorocarbon film (CF_x)-modified Ag nanoparticles

(NPs)/ITO anode on the performance of OSCs was optimized through theoretical simulation and experimental optimization. This work yielded a promising PCE of $3.5 \pm 0.1\%$, notably higher than that with a bare ITO anode ($2.7 \pm 0.1\%$). The work was extended to study the performance of OSCs made with CFx-modified Ag NPs/ITO/polyethylene terephthalate (PET) substrate. The resulting flexible OSCs had a relatively high PCE of $3.1 \pm 0.1\%$, comparable to that of structurally identical OSCs fabricated on ITO-coated glass substrate (PCE of $3.5 \pm 0.1\%$). The distribution of the sizes of the Ag NPs, formed by the thermal evaporation, was over the range from 2.0 nm to 10 nm. The results reveal that the localized surface plasmon resonance, contributing to the broadband light absorption enhancement in the organic photoactive layer, was strongly influenced by the size of Ag NPs and the dielectric constant of the surrounding medium.

A new OSC structure incorporating a transparent PMMA/ITO double layer grating electrode was also developed. 1-D PMMA/ITO double layer grating, fabricated using nano-imprinting and low processing temperature ITO sputtering method, has a period of 500 nm. Light absorption in grating OSCs under TM, TE and TM/TE hybrid polarizations was calculated using FDTD simulation in the wavelength range from 400 nm to 800 nm. We profiled the electric field distribution and analyzed the structural requirement for confining the waveguide modes in the organic photoactive layer. The effects of the periodicity and the pitch size on light scattering, simultaneous excitation of horizontally propagating SPPs, LSPR and the waveguide modes for light harvesting in grating OSCs were analyzed. The efficiency enhancement in the grating OSCs (PCE 3.29%) over the planar control device (PCE 2.86%) is primarily due to the increase in the short-circuit current density from 11.93 mA/cm^2 to 13.57 mA/cm^2 (13.7% enhancement). The theoretical results agree with the experimental findings in showing that the improved performance in grating OSCs is attributed to the absorption enhancement in the active layer.

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