DOCTORAL THESIS

Broadband light absorption enhancement in organic solar cells

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Date of Award:
2014

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 MoO_3/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:C_{60}-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 (CFx)-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 ± 0.1%, notably higher than that with a bare ITO anode (2.7±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±0.1%, comparable to that of structurally identical OSCs fabricated on ITO-coated glass substrate (PCE of 3.5±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.

Acknowledgement

First, I would like to express utmost gratitude to my supervisor Prof. Furong Zhu, for introducing me to the organic solar cell field and offering the great opportunity of taking part in the research work related to organic electronics. During the period of my Ph.D. studies, I have benefited a lot from his continuous guidance, not only in acquiring knowledge technically but also in the precise attitude for academic research. This thesis could not be completed without his selfless advice.

I would like to thank the members from our research group: Dr. Hoi Lam Tam, Mr. Wing Kin Chan, Dr. Bo Wu, Mr. Wing Hong Choi, Mr. Zhenghui Wu, Mr. Hanxiao Liu, Miss Weixia Lan, Mr. Yanlian Lei and Mr. Min Hsuan Lee, for the fruitful cooperation in the research work such as device fabrication and results discussion, and for the support and care in daily life. This is a warm and loving family with a strong academic atmosphere.

I would like to acknowledge the people from the Department of Physics, especially to my co-supervisor Prof. Kok Wai Cheah for his support and assistance in developing my research work. Special thanks also go to: Mr. Tsang Kin Wa, Adam, Ms. Li Yuen Yee, Eve, Mr. Leung Siu Cheong, Benson and Mr. Luk Yu Man, Raymond. The faculty members and friends here have contributed in several ways and make this time an excellent one.

I would also like to thank Dr. Gui Xin Li, Dr. Yanxia Cui and Dr. Xizu Wang, for their generous help on practical experiment and theoretical simulation. Their support in the research work is highly valued. I would like to thank my parents for their continuous support and encouragement for my pursuit in the academic field.

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Hong Kong, August 2014

Table of Contents