PhD Thesis Defense RAFAEL BETANCUR LOPERA 'Photon Control in Nano-Structured Organic Photovoltaic Materials'

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Wednesday, July 10, 11:00. ICFO Auditorium

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Organic nanostructured photovoltaics

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Organic photovoltaic (OPV) technology has emerged as a potential cost-effective solution to produce electrical energy. The foreseen low manufacturing costs combined with features as semi-transparency or mechanical flexibility give to OPV devices a strong potential for industrial applicability. However, the commercial implementation of this technology faces the challenge of increasing the relatively low power conversion efficiency of the current state-of-the-art OPV devices. This thesis presents an optical based approach to enhance the performance of OPV devices by effectively controlling sunlight photons. Such control is possible because of the coherent interaction between light and the multilayered structure constituting the OPV device.

Accordingly, we studied the dependence of the optical field distribution inside the solar cell relative to the optical properties of the different layers including their refractive index n, extinction coefficient k, and thickness. This optical study led to the prediction of optimal OPV device structures. The first implementation of a photon control was done by changing the relative thicknesses of the different layers in the device. An optimal combination of thicknesses was found and confirmed experimentally. A significant reduction of the energy lost in the device was demonstrated. As a consequence, the photon harvesting improved, which led to a close matching between the external and internal quantum efficiencies in a broad wavelength range. A second photon control strategy to enhance the performance of OPV cells was implemented by modifying the complex refractive index of the non-active device layers. Both n and k were changed in specific layers by considering new materials. Three different cases were considered: in the first example a BCP layer was used to replace calcium as electron transporting layer. The parasitic absorption induced by the highly absorptive calcium layer was diminished almost to zero after replacing this layer with BCP, a material whose extinction coefficient is null for a broad wavelength range. A 19% performance enhancement was demonstrated. In the second example, an ultrathin nickel oxide layer was used to replace the commonly used PEDOT layer as hole-transporting layer. Very thin layers of nickel oxide could be used for a better photon distribution and harvesting in the photoactive layer. In the last case, a metallic cupper/nickel semi-transparent electrode was used to replace an ITO electrode. This new metallic electrode in combination with the back aluminum electrode enabled the formation of an optical cavity which resulted in a stronger localization of the field in the active layer.

Finally, several of the concepts considered above to effectively localize the field in the active layer were used in conjunction with a photonic structure integrated in the OPV architecture to achieve an optically optimized semi-transparent OPV device. In particular, a one-dimensional non-periodic photonic crystal was designed and added to a semi-transparent OPV device in order to re-harvest UV and IR photons while keeping a high transmission for the visible photons. A power conversion efficiency enhancement larger than

56% was achieved while maintaining the device luminosity around 30%. An additional feature of the integration of such photonic crystal was the possibility of tuning the color transmitted by the device which was also demonstrated.

In summary, in this thesis we demonstrate experimentally and theoretically that optics plays a very relevant role for enhancing the power conversion efficiency of OPV devices. The methods presented are perfectly compatible with a more oriented material science approach to achieve the final objective of obtaining a performance-competitive OPV technology.

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