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Polarization-diverse, broadband absorption enhancement in thin-film organic photovoltaic devices using metallic gratings

Abstract:
Organic photovoltaic (OPV) devices or plastic solar cells, which convert solar energy into electricity using organic conductive polymers or small molecules, have shown great promise in renewable and green energy applications. Despite their flexibility, lightweight and low-cost, OPVs suffer from low power conversion efficiency (PCE). Recent progresses in the synthesis of new polymers and tandem solar cells promoted the PCE to 10.6% in Feb 2012, which is a great leap from the 2.5% in Feb 2001. In thin film solar cells including OPVs, however, the light absorption is intrinsically limited by the thinness of the photoactive layer, especially at wavelengths near the edge of their absorption band. Surface plasmon polaritons (SPPs), a hybrid of electron density oscillations and optical waves at dielectric/metal interfaces, have great potential in overcoming the limit in light absorption for three reasons. (1) SPPs are highly evanescent. When generated at the photoactive layer/metal electrode interface, SPPs benefit the optical absorption in thin-film solar cells by concentrating optical waves and their electromagnetic energy near the photoactive layer. (2) SPPs propagate along the supporting interface, which can be utilized to change the light path. As the light propagates sideways along the photoactive layer, the light path and thus the absorption is effectively increased. (3) SPPs have unique and tunable dispersion relations, i.e. their propagating speed and effective index can be controlled. This can be useful in engineering and combining the SPPs with other photonic phenomena for the absorption enhancement.

In this thesis, I proposed to use Ag gratings to enhance the optical absorption of P3HT:PCBM based OPVs. To implement the Ag gratings in OPVs, we designed an inverted OPV architecture with light impinging on the device directly from the air side, in contrast to the traditional OPVs with light impinging on the transparent substrate first and then the device.

I showed, through finite element method (FEM) simulations, that with proper design of the grating geometry, we can achieve light absorption enhancement for linearly polarized light with all polarization angles, despite the fact that the Ag gratings are periodic only in one direction. The generation of propagating SPPs and the waveguiding modes in the photoactive layer, are revealed as the two absorption enhancement schemes. Ag gratings are fabricated with electron beam lithography (EBL) or UV laser inteferometric lithography combined with a lift-off process. The gratings and the OPVs with grating substrates were characterized with a micro-spectrometer, which showed 200% enhanced absorption at ~ 690 nm with the optimized grating design. The roles of the grating pitch size, duty cycle and the height on the absorption enhancement were also studied with numerical analysis and experimental confirmation.

In addition, this thesis also discusses the OPV device performance and the future prospective of plasmonics assisted thin film solar cells.