Embedded Light Management Films for All-season Energy-harvesting in Printed Photovoltaics

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Applying light management on the device surface is a favorable method for efficiency enhancement, since it avoids complications with the delicate printing of the photovoltaic layers. Previously proposed structures, however, have their functional interface exposed to environmental impacts and stress. Here we demonstrate a photonic nanostructure that is able to increase the total yearly harvested energy by 13%. The nanostructure is embedded in a transparent film, providing a conformal light management device attachment that is protected from environmental exposure and dust.

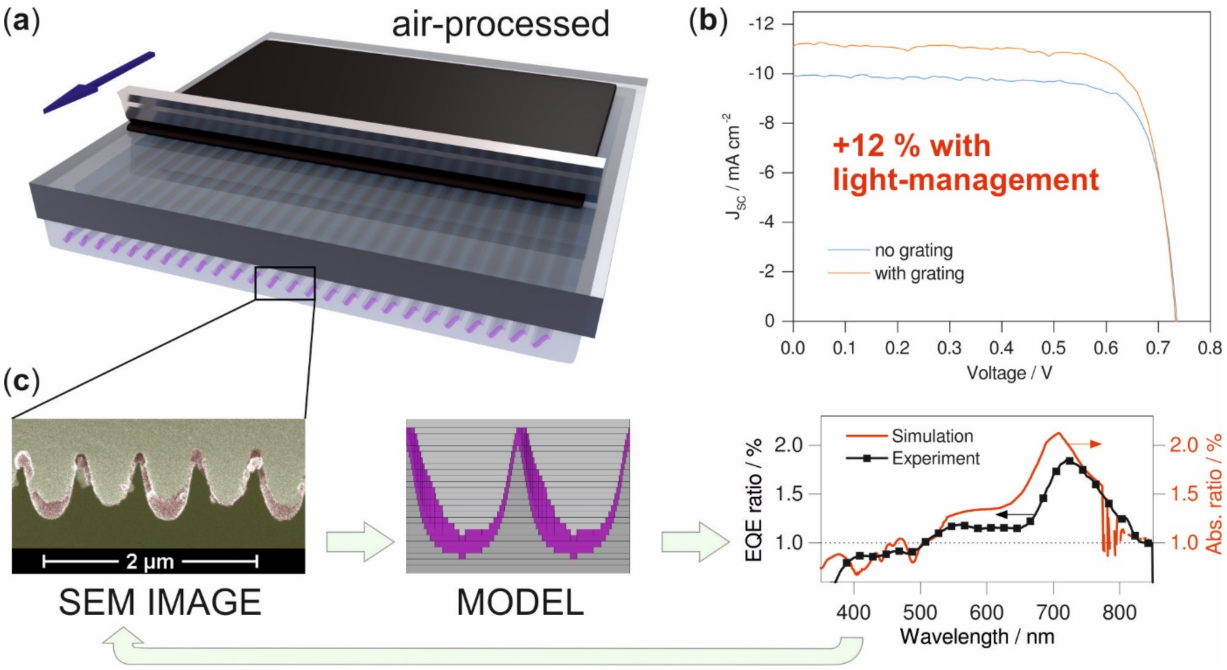

Figure 1: (a) Photovoltaic test cells are printed on a modified substrate with an attached light-management layer. Through light redirection via elaborated diffraction properties, the absorption in the absorber is enhanced and (b) a 12% increase in the efficiency is obtained. (c) A simulation platform was developed to predict, explain and design the impact of the photonic nanostructures for a given cell architecture and use case.

Organic photovoltaics (OPV) have recently reached over 11% power conversion efficiency (PCE) in single-junction and 13.2% in multi-junction cells, continuing their route towards commercialization. To further advance this progress, light management (LM) for organic photovoltaics has attracted increasing interest as an additional route besides material development and process and morphology engineering. It has been emphasized recently, however, that certain key aspects are crucial for a successful implementation of light management in printed thin film photovoltaics,[1] namely i) avoiding electronic losses or parasitic absorption ii) developing structures that are cost effective in the integration and compatible both with mass-manufacturability and outdoor operation and iii) considering the integrated energy harvested throughout a full year, rather than only under standard test conditions (STC).

We therefore developed an elaborated diffractive nanostructure which provides a solution to these central points with an economically attractive enhancement-per-cost ratio. Figure 1a shows the printing of organic solar cells, which is independent from the LM layer that is attached on the light incident side of the substrate.[2] Consequently, the morphology of the active layers, which is known to influence the electrical properties of the device, is not affected and the absorption enhancement induced by the LM act directly on the efficiency (Figure 2b). Furthermore, the embedded LM films are protected against environmental influences and can be fabricated on large scales, for example integrated in a roll-2-roll production line.

A simulation platform was developed (Figure 1c), which is able to reproduce the absorption enhancement under STC in multiple devices (with an internal quantum efficiency assumed to be unaffected by the LM). It is observed that an overestimation of the enhancement arises from the limited geometrical extent of the charge collecting electrode. An even more effective collection of trapped light can thus be expected on larger scales.

Motivated by the good agreement of the spectral enhancement with the simulations under STC, an estimation of the full year current generation is given. Accounting for hourly spectrum, zenith and azimuth angle of a full year (clear sky), an increase in the harvested energy of up to 13% is predicted. Moreover, it is shown how the grating properties can be tailored by several parameters to take into account the illumination conditions of various application cases (automotive, facade, consumer electronics, shading) enabling the customization and optimization of the yearly energy harvesting capability.

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[1] Nat. Nanotechnol., 9, 19-32 (2014); Nat. Mater., 13, 451-460 (2014; Energy Environ. Sci., 7, 2123 (2014).

[2] J. Mayer, *et al*., Opt. Express 24(2), A358-A373 (2016); submitted.