Light Management for OPV

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Optical in-coupling gratings are designed and tested to improve the performance of thin film organic photovoltaics. The impact of the grating on the absorption in the active layer has been modeled and explained using a standard OPV cell architecture. Simulations predict an increase in absorption of up to 20 %, which shows to be independent from the chosen absorber material. Different structures have been applied on blade-coated devices and an efficiency improvement of 12 % could be validated. The angular performance of the structures was further measured, showing an increased stability of the enhancement for two dimensional gratings. In simulations of the current generation for different angles and illumination conditions, a total yearly increase of the harvested energy of 12 % is predicted, using an optimized grating. The fabrication of these structures, moreover, is compatible with roll to roll production techniques, which makes them an optimal solution for printed photovoltaics.

Organic photovoltaics (OPV) represent an emerging technology, which can enable cost-effective, flexible and light-weight energy-harvesting and which allows for fabrication with established printing techniques, like roll-to-roll. A remaining drawback, however, is the limited absorption of the thin polymer layers, which can be addressed by the use light-management structures, which increase the portion of the light that is absorbed in the device.

Most approaches for nanophotonic light-trapping thereby have a direct impact on the fabrication processes and the device architecture. [1] Since diffraction gratings can be added on top of the light-incident interface (Figure 1), they can be fabricated fully independent from the OPV and therefore exhibit high potential for integration into roll-to-roll production. Moreover the gratings can be functional even when embedded into a matrix, which then provides protection against external environmental influences (e.g. scratching, dust, moisture).

In this work the optical interplay of the gratings and the multilayer stack was studied and revealed that in the thin films of OPVs the origin for the strong enhancement is not only the increased path-length, but also constructive interferences, which can be accessed with the diffracted light of the surface grating. Consequently, the resulting absorption enhancement induced by the grating is linked to the stack architecture and does not depend on the active material, which largely dominates the power conversion efficiency.

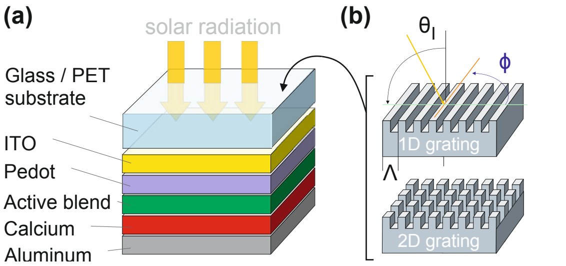

Figure 1: (a) Standard device architecture of an OPV. (b) A sub-micrometer line grating (1D) or crossed grating (2D) is fabricated at the light incident surface of the device.

The validation of the structures on blade-coated photovoltaic devices showed an enhancement of 12 % with respect to the reference which had an efficiency of 5.2%, measured under standard test conditions and straight incident light. Simultaneous computations and experiments are ongoing to further optimize these structures to exceed the predicted enhancement of 20 %. However, besides maximizing the absorption for straight incidence under AM 1.5G solar illumination, a more general solution is pursued, accounting for the different ambient conditions in the final application. In angular dependent measurements of the generated current, especially the 2D grating has shown a good performance with low dependency on the incident polar and azimuthal angles, θ and ϕ.

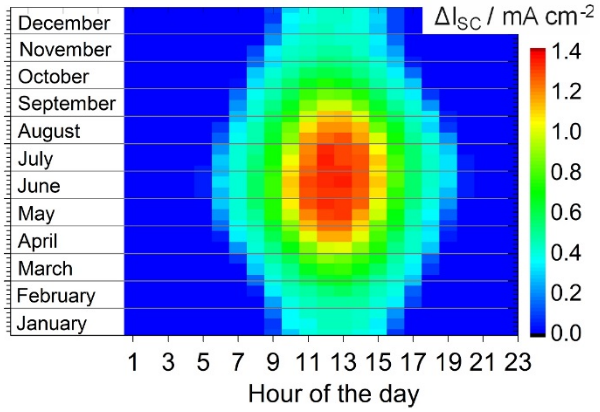

Figure 2: Hourly increase in the generated current for the standard OPV equipped with an in-coupling grating.

These results were used to model the hourly current generation over 365 days by considering also the respective illumination spectra in the location of Basel, Switzerland, obtained from the NREL database (Figure 2). By this means, a total yearly increase in harvested energy of 12 % could be simulated using the 2D in-coupling grating.

Continuing from the promising results of this proof-of-concept study, in a next step this added value of increased light-harvesting will be transferred on foils, which can be structured with diffraction gratings via hot-embossing (Figure 3).

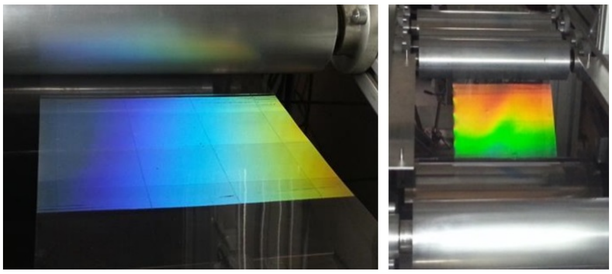

Figure 3: Hot-embossed diffraction grating as prospective light-management structure for roll-to-roll processed organic photovoltaics.

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[1] J.-D. Chen, C. Cui, Y.-Q. Li, L. Zhou, Q.-D. Ou, C. Li, Y. Li, J.-X. Tang, "Single-junction polymer solar cells exceeding 10 % power conversion efficiency", Adv. Mat. 27 (2014) 1035