

On the angular dependent nature of absorption enhancement in solar cells by metallic nanostructures

**Aimi Abass¹, Honghui Shen², Khai Q. Le², Peter Bienstman²,
and Bjorn Maes^{2,3}**

¹ *Solar Cell Group, Department of Electronics and Information Systems (ELIS), Ghent University-IMEC, B-9000 Ghent, Belgium*

² *Photonics Research Group, Department of Information Technology (INTEC), Ghent University-IMEC, B-9000 Ghent, Belgium*

³ *Micro- and Nanophotonic Materials Group, Institut de Physique, University of Mons, B-7000 Mons, Belgium*

aimi.abass@elis.ugent.be

The usage of metallic nanostructures for absorption enhancement in thin film solar cells has been widely and thoroughly investigated in recent years [1,2]. Designing the optimum optical structure is not straightforward as there are various photonic phenomena having complex interaction with each other excited by the metal nanostructures. Here, we explore various possible ways of optically enhancing photovoltaic cells by incorporating periodic metallic structures. We numerically demonstrate a strongly enhanced light absorption exploiting a complex interplay between multiple electromagnetic wave phenomena, among which surface plasmon polariton (SPP) resonances, waveguide mode resonances, Fabry-Perot modes, and scattering. The particular opportunities to obtain a good angular performance of the absorption enhancement are discussed. In addition, we introduce a novel multiperiodic geometry that incorporates multiple types of SPP resonances which have a flat dispersion.

To achieve a good angular performance of the absorption enhancement, we studied the field profile characteristics of the photonic modes generated and study its dependence on the structure's geometry. Depending on the structure, operating the solar cell at a certain tilt with respect to the incoming light incidence can also be favorable as it can lead to more photonic modes being excited than with normal incidence. Gratings with pronounced geometry compared to the active layer thickness is found to be of interest as they give SPP modes with flat dispersion and thus less angle sensitivity. Extra care has to be taken when waveguide modes are also incorporated, as we show they can interfere destructively with the SPP modes. Further enhancement in the off resonance wavelength region can be achieved by light scattering induced again by the metallic grating structure.

All these photonic design considerations are thoroughly discussed and the strategy formulated can essentially be used and adapted for other types of solar cell materials. We show some of the results of our calculations in which absorption

enhancement is achieved with a triangular back grating structure. Fig. 1(a) shows the absorption spectrum in the active polymer layer $A(\lambda)$ of a P3HT:PCBM polymer film with a 1D triangular back grating. The grating structure gives a 15.4% increased integrated absorption of the AM1.5G spectrum in the 300–800 nm wavelength range for TM polarization. As seen in the field profile in Fig. 1(b), we incorporate a mode in the polymer (A) and SPP modes (B&C) to obtain absorption enhancement. The resonance B only appears at angled incidence. For the multiperiodic grating case a significant further increase of integrated absorption by 20.7% for TM is demonstrated, as shown in Fig. 2(a). It is also shown in Fig. 2(b) how the modes excited here are angle insensitive.

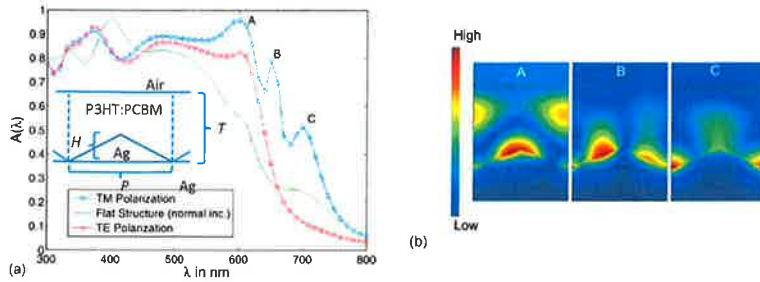


Figure 1. Employing plasmonic and polymer modes with $T=250$ nm, $P=290$ nm, $FF=1$ (Fill factor), $H=60$ nm. (a). Absorption spectrum $A(\lambda)$ of the active polymer layer for the grating cell with $\theta = 13.5^\circ$, compared with $A(\lambda)$ for a planar structure of 250 nm polymer with normal incidence. (b) Field profile of the norm of the magnetic field at the three peaks in (a).

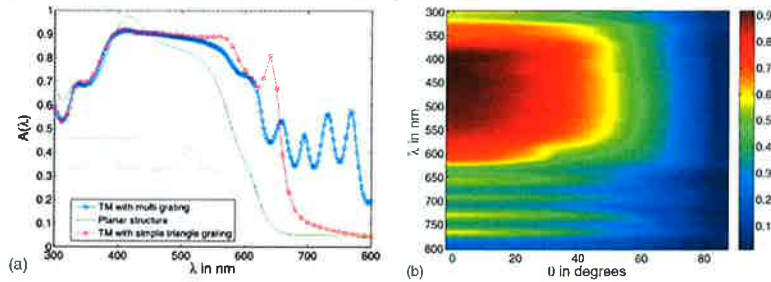


Figure 2. $A(\lambda)$ for a grating with extra smaller defects (main period 390 nm, small period 30 nm, main triangle height 120 nm, and $T=150$ nm), the defect groove depth is 15 nm on average, with 2 nm rounding of the sharp tips. The FF for the main grating is 0.5 and for the defects it is 1/3. (a) $A(\lambda)$ for perpendicular incidence. The plot for the case without additional defects, and for a planar structure with 150 nm polymer thickness are also provided. The inset shows the geometry. (b) $A(\lambda)$ vs the angle of incidence.

References

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- [2] H. Atwater and A. Polman, *Nature Mater.* **9**, 205213 (2010).

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