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ADVANCED DESIGN RULES FOR NANOPHOTONIC THIN FILM SOLAR CELLS

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1) Context / Study motivation

Thin film crystalline silicon (c-Si) solar cells are one of the most promising candidates for low cost photovoltaic. Considering material costs issues, the thickness of the c-Si layer should be as small as possible [1, 2].

Nanophotonics structures have emerged as a promising way to enhance light trapping in thin film solar cells. Among the various concepts that have been proposed, Photonic Crystals (PC) can now be integrated in a solar cell stack, as a deep corrugation of the active layer.

The very first results show an improvement of the short-circuit current and of the efficiency compared to the unpatterned reference cell [3]. However, these first results suffer from a lower open circuit voltage. This is attributed to an insufficient passivation of the additional etched surfaces.

In this paper, we report on further optimization of the absorption through light management which is essential to achieve high conversion efficiency.

More precisely, three ways of improvement detailed in this communication can be followed to increase the efficiency of thin film c-Si solar cells.

2) Description of approach and techniques

Two complementary approaches can be used to provide the required understanding.

The first is a phenomenological method to analyze the effect of resonant optical modes. Indeed, the time domain coupled mode theory (TDCMT) [4] can be used to determine the optimal modal properties to maximize absorption not only at the resonance wavelength of modes [5], but also all over the spectral range

The second is the Finite Difference Time Domain Method (FDTD) method to calculate rigorous electromagnetic fields at any point in the structure and thus to obtain the photocarrier generation rate for electrical simulation [2].

3) Results / Conclusions / Perspectives

Due to the material dispersion properties, three main mechanisms of light collection and trapping can be identified (Fig. 1): anti-reflection (AR) effects for wavelengths lower than about 450 nm, Fabry-Perot effect (FP) for wavelengths ranging from 450 nm to 600 nm, and for larger wavelengths, where the material absorption is low, light coupling into with slow Bloch modes of the photonic crystal.

The phenomenological description using TDCMT shows that the usually admitted critical coupling condition is not the optimal condition to maximize the integrated photon absorption by the Bloch Modes. A larger coupling of the Bloch modes is preferable to enable a lower but far broader absorption (Fig. 2) [6]. Then, providing the mode density of the structure is high enough, absorption can be enhanced.

For wavelengths shorter than about 450 nm, the penetration depth is less than the thickness of the layer due to the high values of absorption coefficient in the region. Therefore, it is not possible to excite modes FP or slow Bloch modes.

The increase in absorption in this region is usually explained by the decrease of the effective index resulting from the structure of the absorbing layer.

However, a more complex behavior is observed, with a high density of light into the holes, and then at the interfaces (Fig. 3). To retrieve all of the electromagnetic field a very good passivation is required

For wavelength larger than 650 nm, actually, light should be always confined away from the highly doped to improve the internal quantum efficiency. [7]

All these design rules will be taken into account for the future development of high efficiency nanophotonic thin film solar cells.

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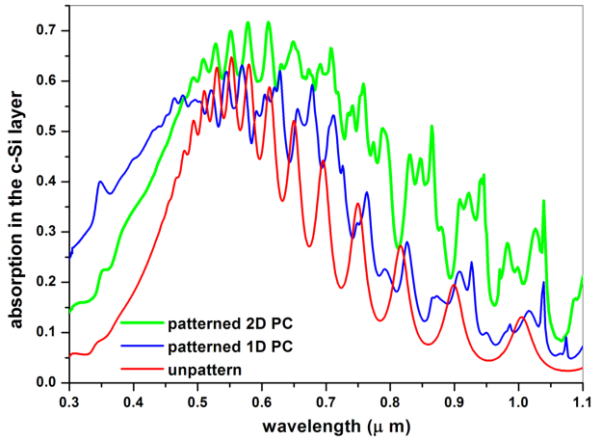


Figure 1: Simulated absorption spectra in the c-Si layer of PC and reference thin film solar cells. [1]

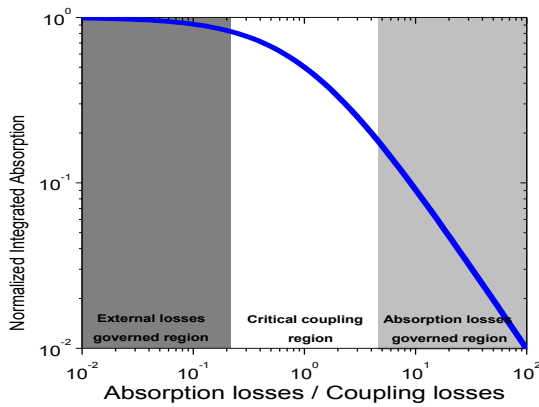


Figure 2: Integrated absorption as a function of losses in a single mode PC membrane calculated using TDCMT.

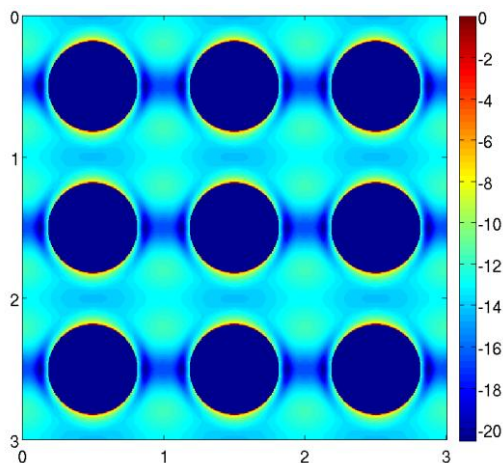


Figure 3: Top view of the FDTD calculated absorption map depicted over three periods of the PC at low wavelengths in a 2D absorbing PC membrane.

REFERENCES:

- [1] X.Meng *et al.*, "Design fabrication and optical characterization of photonic crystal assisted thin film monocrystalline-silicon solar cells". *Optics Express*, 20(S4):A465-A475, 2012.
- [2] G.Gomard *et al.*, "Light harvesting by planar photonic crystals in solar cells: the case of amorphous silicon", *Journal of Optics*. 14,024011, 2012.
- [3] Christos Trompoukis *et al.*, "Photonic assisted light trapping integrated in ultrathin crystalline silicon solar cells by nanoimprint lithography", IMEC, *Applied physics Letters*, 2012.
- [4] H.A.Haus. "Waves and Fields in Optoelectronics". Englewood Cliffs, 1984.
- [5] R.Peretti *et al.*, "Modal approach for tailoring the absorption in a photonic crystal membrane", Université de Lyon, Institut des Nanotechnologies de Lyon (INL), Ecully 69134, *Journal of Applied physics*, 111, 123114, 2012
- [6] G.Gomard et al. "Photonic crystals and optical mode engineering for thin film photovoltaics". *Optics Express*, 21(S3):A515-A527, 2013
- [7] Michael G. Deceglie *et al.*, "Design of Nanostructured Solar Cells Using Coupled Optical and Electrical Modeling", Thomas J. Watson Laboratories of Applied Physics, California Institute of Technology, Pasadena, California 91125, United States, *Nano Letters*, 12, 2894-2900, 2012.