3D-FDTD Analysis of Absorption Enhancement in Nanostructured Thin Film Solar Cells

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Summary:

Abstract: We investigate 1D-2D photonic crystals for light absorption enhancement on thin film photovoltaics (Si, GaAs and InP) by FDTD. A comparison with RCWA and TMM is presented. The absorption is increased substantially for these systems.
OCIS codes: (160.5298) Photonic crystal; (310.6845) Thin film devices and applications; (040.5350) Photovoltaic.

Introduction

Thin film solar cells solar cells made out of either inorganic/organic material are of an increasing importance. Despite of their small thickness they can be optimized in order to efficiently use the incident light to improve absorption. Nanostructuration of the surface in form of a periodic pattern like a photonic crystal has been demonstrated to improve them [1]. Nevertheless, a deep understanding on what are the physical mechanisms for the improvement is needed. In order to obtain a deeper insight on these mechanisms, we have developed around the free available software MEEP [2] to model the optical properties of nanostructured solar cells including photonic crystal structures. Three dimensional FDTD simulations have been used to calculate the optical absorption, transmission and reflection on such systems. Comparison with other methods like RCWA and TMM has been also performed.

Results

The main advantages of using FDTD codes for the modeling of nanostructured solar cells are its rigorous solutions and a higher flexibility for the design of structures. Our calculations have been compared with the transfer matrix method (TMM) [3] and the rigorous coupled wave analysis (RCWA) [4], [5] showing compatible results. We have studied nanostructured materials in 1D (nanorods) and in 2D (nanopillars) forming a square-lattice photonics crystals, with and without an underlying substrate. Analysis with the polarizations (S-P and pseudo-unpolarized) and with the angle of incidence has been also evaluated.

The materials are simulated realistically using a complex variable refraction index over frequency. Thicknesses between 100 nm and 1000 nm are studied for crystalline silicon, amorphous silicon, gallium arsenide and indium phosphide. Optical absorption (A=1-R-T) is calculated using monitors for transmission and reflection. As an example, a typical surface-nanostructured layer with a 2D photonic crystal is shown in Fig. 1. The structure in this case is composed of a silicon amorphous substrate with a thickness of 150 nm with nanopillars 150 nm tall. It is compared with the same structure without photonic crystal with a thickness of 300 nm thick and including an anti-reflective coating (ARC) 70 nm thick. There is an improvement in the absorption of the nanopatterned structure despite the mass of absorbing material is only a 60% of the structure without nanostructuration. Absorption is normalized to a perfect absorbing system. For most of the energies of normally incident light the nanopillar photonic crystal surface increases the absorption around a 5% in respect to the same structure without photonic crystal but with an ARC.

References

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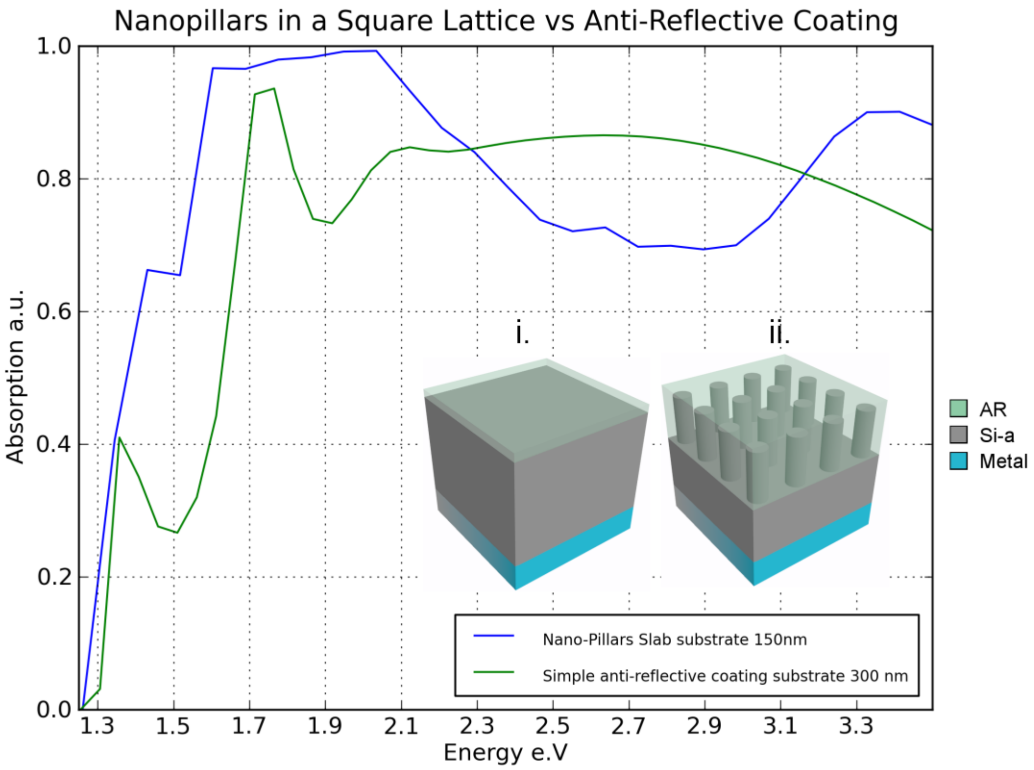

Fig. 1. Absorption of the structure shown in the inset (i. Substrate 300 nm with anti-reflective coating d=70nm and metal layer ii. A square lattice of nanopillars with lattice parameter a=450 nm and diameter d=225 nm).

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