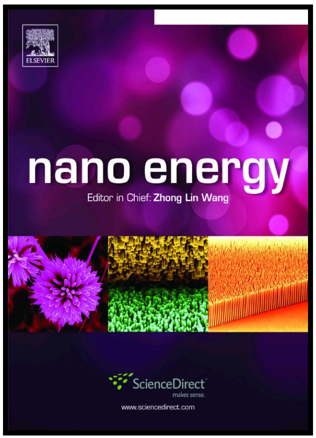
www.elsevier.com/locate/nanoenergy

Design of optimized wave-optical spheroidal nanostructures for photonic-enhanced solar cells

Manuel J. Mendes, Andreia Araújo, António Vicente, Hugo Águas, Isabel Ferreira, Elvira Fortunato, Rodrigo Martins

PII: S2211-2855(16)30160-4
DOI: http://dx.doi.org/10.1016/j.nanoen.2016.05.038
Reference: NANOEN1303

To appear in: *Nano Energy*

Received date: 25 February 2016
Revised date: 18 May 2016
Accepted date: 22 May 2016

Cite this article as: Manuel J. Mendes, Andreia Araújo, António Vicente, Hugc Águas, Isabel Ferreira, Elvira Fortunato and Rodrigo Martins, Design o optimized wave-optical spheroidal nanostructures for photonic-enhanced sola cells, *Nano Energy,* http://dx.doi.org/10.1016/j.nanoen.2016.05.038

Design of optimized wave-optical spheroidal nanostructures for photonic-enhanced solar cells

Manuel J. Mendes, Andreia Araújo, António Vicente, Hugo Águas, Isabel Ferreira, Elvira Fortunato, Rodrigo Martins

i3N/CENIMAT, Department of Materials Science, Faculty of Science and Technology, Universidade NOVA de Lisboa and CEMOP/UNINOVA, Campus de Caparica, 2829-516 Caparica, Portugal

Abstract

The interaction of light with wavelength-sized photonic nanostructures is highly promising for light management applied to thin-film photovoltaics. Several light trapping effects come into play in the wave optics regime of such structures that crucially depend on the parameters of the photonic and absorbing elements. Thus, multi-parameter optimizations employing exact numerical models, as performed in this work, are essential to determine the maximum photocurrent enhancement that can be produced in solar cells.

Generalized spheroidal geometries and high-index dielectric materials are considered here to model the design of the optical elements providing broadband absorption enhancement in planar silicon solar cells. The physical mechanisms responsible for such enhancement are schematized in a spectral diagram, providing a deeper understanding of the advantageous characteristics of the optimized geometries. The best structures, composed of TiO_2 half-spheroids patterned on the cells' top surface, yield two times higher photocurrent (up to 32.5 mA/cm^2 in 1.5 μm thick silicon layer) than the same devices without photonic schemes.

These results set the state-of-the-art closer to the theoretical *Lambertian* limit. In addition, the considered light trapping designs are not affected by the traditional compromise between absorption enhancement versus current degradation by recombination, which is a key technological advantage.

Keywords: Photovoltaics; Wave-Optics; Nanophotonics; Light Trapping; Thin Film Solar Cells; High-index Dielectric Scatterers

1. Introduction

The large mismatch between the light absorption depth and the carrier diffusion length, in deposited thin semiconductor films, makes light management crucial for the realization of high-efficient (>25%) and inexpensive (<0.5$/W) non-wafer-based solar cells [1]. Optimized light trapping (LT) strategies have the potential to strongly boost the optical absorption in the thin solar cell material, thereby enhancing the efficiency and allowing the thickness reduction. Optically-thicker but physically-thinner devices imply cheaper and faster fabrication, and also improved flexibility which is important for roll-to-roll manufacturing [2] and their application in bendable substrates (e.g. paper [3], polymers, tissues, etc.) aimed for consumer-oriented products (sun-powered intelligent packaging [4], wearable PV, portable electronics, etc). In addition, for cells not limited by surface recombination, a reduction in their thickness can lead to higher open-circuit voltages (and consequently efficiencies) due to lower bulk recombination [5].

The conventional LT approach is the insertion of textured surfaces at the rear or front of the solar cells, to diffuse light and thus increase its optical path length within the absorber layer [6-9]. In the last decade, a variety of more advanced strategies have been proposed employing: self-assembled plasmonic metal nanoparticles [10, 11],