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Potential of diffraction gratings for implementation as a metal back reflector in thin-film silicon solar cells

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Abstract

In thin-film silicon solar cells, novel approaches of light management are important in order to further improve the light confinement in the cells. In this work the potential of the metal periodic diffraction gratings as a back reflector in a microcrystalline silicon-based solar cell is investigated by means of two-dimensional numerical simulations. Two different shapes of the gratings – rectangular and triangular – are included. A de-coupled analysis of two effects, related to the shape and the size of the gratings are investigated: a) the enhancement of the light scattering due to grating and b) the effect of decreased total reflectance (increased optical losses) in the realistic metal silver grating. The results on the partial solar cell structures show significant increase in the scattering, (up to 130 – 180% increased absorptance) especially for the periods around 1- and 2-times the effective light wavelength in the microcrystalline silicon absorber. However, high reductions in the total reflectance (up to 40%) are indicated for the realistic silver gratings, compared to the flat silver back reflector. Triangular diffraction gratings exhibit the potential for optimization over a longer wavelengths range than rectangular gratings.

Keywords: Solar cell; Optical simulations; Diffraction gratings; Back reflector

1. Introduction

In thin-film silicon (TF Si) solar cells efficient light management is essential in order to obtain sufficiently high photocurrent from the thin absorber layers in the cells (thicknesses from 200 nm to a few μm). Optimization of the existing optical solutions and the design of novel optical concepts are important to raise up the efficiency of the TF solar cells. For the design of novel concepts, optical modeling supported by the computer simulations presents an essential tool [1]. In this paper, modeling and simulations are utilized to investigate the concept of metallic diffraction gratings in the role of a back reflector (scatterer) in the thin-film microcrystalline Si (μc-Si:H) solar cells. In the μc-Si:H solar cells such new approaches, aiming to enhance the light scattering, are extremely important, since there exists a wide wavelength range of spectrum (600 – 1100 nm) which can be absorbed in the μc-Si:H material only by achieving noticeable prolongations of the optical paths in the thin layers.

In our approach two-dimensional (2D) numerical simulations, based on the finite element method (FEM) are used to investigate the internal optical situation in the μc-Si:H absorber in the cells with the diffraction gratings back reflector. Potential improvements in the absorption, due to an efficient light scattering, are analyzed for the case of two different types of periodic diffraction gratings − the rectangular and the triangular. The two different types of the periodic gratings have already been investigated separately [2–6]. However, despite the indications of a high potential of the light scattering assigned to the gratings [2], there still exists a question how to gain the absorption from this potential in TF Si solar cells. The so far reported TF Si solar cells including the periodic gratings have not reached the performances of the cells deposited on the optimized randomly textured substrates yet [4]. Further investigations including an inside view in the optical situation in the TF solar cells are required.

A de-coupled analysis of the two optical effects, which we found to be important for the metallic gratings in TF cells, is carried out here: (a) enhancement of light scattering inside the μc-Si:H absorber and b) effect of increased optical losses (decreased total reflectance) in the metal silver (Ag) grating.

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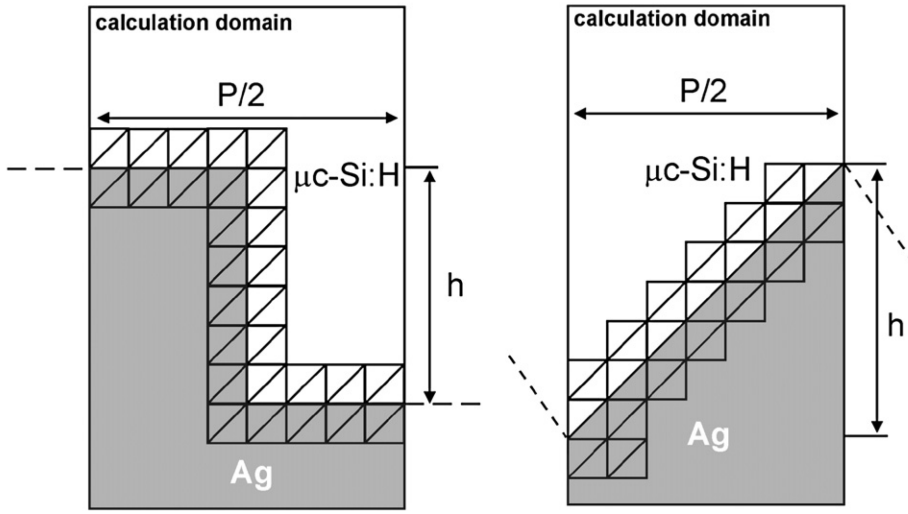

Fig. 1. Schematic pictures of the simulated gratings with denoted discretization elements at the μc-Si:H/Ag interface for the rectangular (left) and the triangular grating (right).

Partial TF structure (only a simple stack of μc-Si:H/Ag grating) was used in simulations to clarify the above mentioned effects.

Optimal periods and heights of the periodic gratings, regarding the scattering, are shown. Relatively high optical losses in the gratings with the optimal parameters for the scattering are indicated. Thus, a trade-off between efficient scattering and low absorption in the metal (high reflectance) is discussed. Comparison between the rectangular and the triangular shape of the gratings is made, regarding the scattering and the decreased total reflectance of the grating. Results of simulations are presented for a selected long-wavelength of 800 nm, however the extension of the observations to a broader long-wavelength range is discussed.

2. Simulation details

In our FEM simulator the discretization is based on the triangular elements making the possibility of perfect fitting to the grating geometry of rectangular and triangular shape of the grating lines (Fig. 1). In simulations at least 50 discrete elements were used per effective wavelength (λ_{eff}) in the material. Due to the symmetry only half of the period was simulated. The periodical structure was illuminated under normal incidence. The periodical boundary condition (homogeneous Neumann condition) was used in simulations at the left and the right boundary [7]. The simulations were done for both polarizations, transverse electric (TE) and transverse magnetic (TM). Equal representation of both polarizations was considered.

3. Results

The effect of enhanced light scattering (a) and the effect of decreased total reflectance (b) in a periodically textured Ag grating, as a back reflector in a TF μc-Si:H-based solar cell were investigated separately. To eliminate all other effects (e.g. multiple reflectances at the other interfaces in the solar cell structure) and to clarify the influence of the effects (a) and (b) only, the following simple simulation stack was proposed in this work: intrinsic μc-Si:H layer (presenting the absorber) on the top of the Ag grating (presenting the back reflector) (Fig. 2). We were able to exclude the role of reflectances at the front air/i-μc-Si:H interface for the above mentioned reasons. In the case of the study of the effect (a) the increased absorptance in the 1 μm thick μc-Si:H zone above the grating was chosen for the detection and direct indication of the enhanced scattering. For the effect a) a perfectly reflective grating (with the unity reflectance) was included in these simulations. For the effect b) a realistic Ag grating was used to indicate the effect of decreased reflectance at the grating.

Here the results of the simulations for the wavelength of 800 nm are presented. Quantum efficiency plots of the μc-Si:H solar cells show that enhanced scattering around this

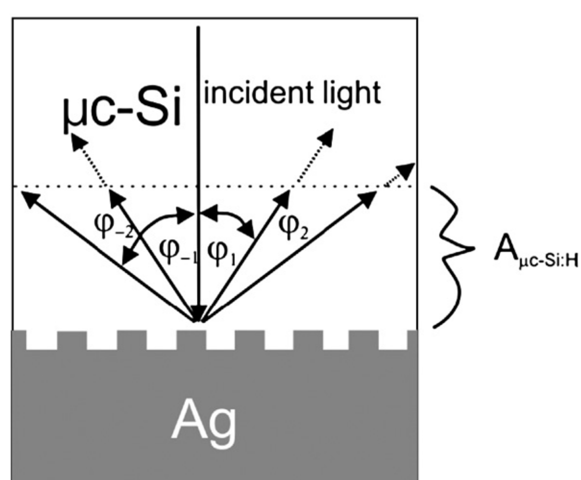

Fig. 2. Light scattering at the grating interface.