Photon Management Structures for Solar Cells – From Modeling to Fabrication

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Summary

Photon management structures are of increasing importance for solar cells. A coupled wave-optical and electrical simulation approach is introduced. Furthermore, fabrication technologies based on interference and nanoimprint lithography are presented. Simulation and experimental results are shown for an exemplary system.

Introduction

In photovoltaic energy conversion, there are two major goals: thinner solar cells and higher quantum efficiencies. It is, however, challenging to reach these goals at the same time. For this reason, photon management structures for light trapping are of increasing importance. Such structures can be front side textures, back side diffractive gratings or metal nanoparticles for plasmonic effects [1]. For the optimization of solar cells with photonic structures, electro-optical modeling is necessary. For the application, cost effective manufacturing technologies are needed.

An exemplary system is a crystalline silicon solar cell with a backside diffractive grating. The basic idea is that the grating diffracts light at the rear surface. The diffraction results in enhanced light path lengths within the silicon and, consequently, increased absorption [2].

Modeling

The combination of electrical semiconductor device modeling and the wave-optical description of the photonic structures is not yet established as a standard method. In order to use computation power efficiently, choices in terms of simulation approach and reduction of complexity have to be made. We have developed a method that directly combines Rigorous Coupled Wave Analysis (RCWA) and Sentaurus TCAD. As a second option, we have evaluated the combination of RCWA and ray tracing algorithms. With these methods, we performed an optimization of parameters for the rear side grating and obtained predictions for the improved solar cell efficiency.

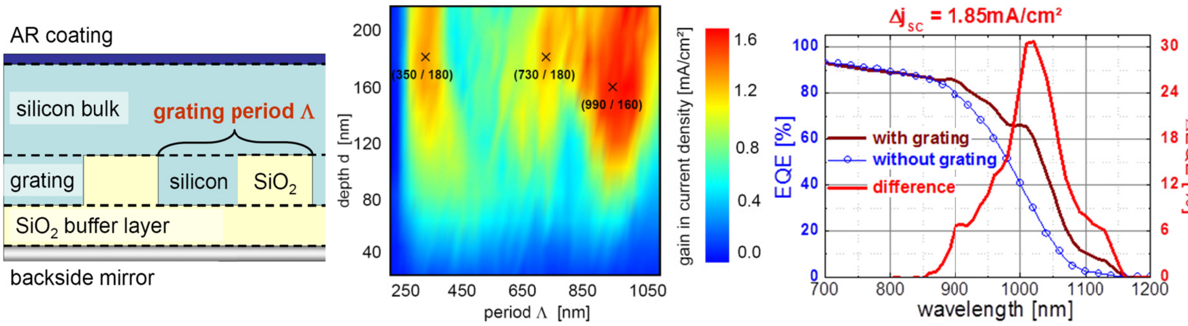

Fig 1: Left: Investigated system: 40 µm thick silicon solar cell with a linear grating on the rear side. Center: Wave optically calculated gain in photocurrent in dependence of the grating period and depth. Right: Simulated quantum efficiency of a corresponding solar cell (grating period: 990 nm, structure depth: 160 nm). An efficiency increase of 1% absolute is predicted [3].

Fabrication via interference and nanoimprint lithography

Interference lithography is a very versatile process for the origination of micro- and nanostructures. One- two- or three-dimensional structures can be originated using the interference of two or more coherent waves. The strength of the technology is that very large samples (up to 1.2 x 1.2m^2) can be structured homogeneously [4].

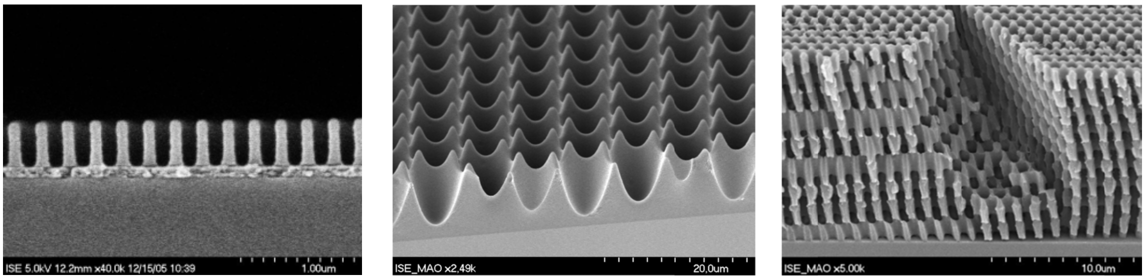

Fig 2: SEM micrographs of surface reliefs originated by interference lithography. Left: Linear grating of a period of 200 nm. Middle: Hexagonal grating as used for the front side honeycomb texture. Right: 3D-photonic crystal fabricated by four-wave interference lithography.

The very demanding interference lithography is the starting point for an industrially feasible process chain. The originated master structures are used as templates for subsequent nanoimprint lithography processes. In our process, a flexible stamper is imprinted into a UV curable resist. Afterwards, the resist can be used as an etching mask, as a lift-off layer (e.g. for the production of metal nanoparticles) or as a functional base structure for the deposition of other materials.

For our application example, we produced diffraction gratings in silicon with a period of 1µm. This was realized by using the imprinted resist as a mask for a plasma etching process. The finalized samples then were characterized by reflection measurements and a potential gain in photocurrent density of up to 2.2 mA/cm² could be extracted [5].

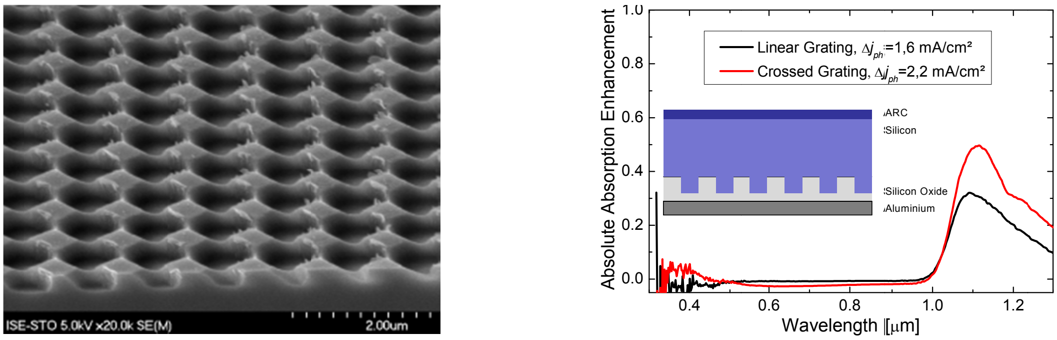

Fig 3: On the left hand side a SEM micrograph of a crossed grating in silicon fabricated via NIL and plasma etching is shown. On the right hand side the measured absorption enhancement introduced by a linear and a crossed grating as well as a sketch of the characterized system is shown.

Conclusions

The efficiency of silicon solar cells can be increased by the introduction of photon management structures. The design of these structures requires combined wave optical and electrical simulation approaches. The combination of interference and nanoimprint lithography allows the fabrication of these structures on large areas in high-throughput processes.

References

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