Structured Metal/Polymer Back Reflectors for III-V Solar Cells

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Timo Aho[1], Tapio Niemi[1], Federica Cappelluti[2], Antti Tukiainen[1], Farid Elsehrawy[2], and Mircea Guina[1]

[1]*Optoelectronics Research Centre, Photonics Laboratory, Tampere University of Technology, P.O. Box 692, FIN-33101 Tampere, Finland*
[2]*Department of Electronics and Telecommunications, Politecnico di Torino, Torino, 10129, Italy*
timo.a.aho@tut.fi

Abstract: We report on fabrication of microstructured metal/polymer back reflectors for light trapping in III-V solar cells. The asymmetric triangular grating provided the highest diffraction of the light when compared to half sphere and cylinder reflectors.
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1. Introduction

Thin-film solar cells are attractive choice for space applications due to their favorable weight-to-power ratio. In thin-film solar cells, depending on specific design and absorber systems, achieving a sufficient absorption length for optimal current generation may prove challenging. For example, in GaInNAs solar cells, the thickness of the absorption layer is limited due to high background doping [1] leading to short carrier diffusion lengths, and in InAs quantum dot solar cells the light absorption in the quantum dot sheets is relatively low [2]. The absorption length and thus the photogeneration can be increased by optical design, i.e. by applying light management to increase the efficiency of solar cells that can be either done in a form of back reflector and/or antireflection coatings (ARCs). With optimized light management, the physical absorption layer thickness can be reduced without sacrificing the current generation enabling fabrication of thinner and lighter solar cells. A simple planar reflector could effectively double the absorption length [3]. However, with a structured back reflector inducing light diffraction, the absorption length can be increased even more [4]. Various approaches to implement structured back reflectors have been published in the literature [5]. Here, we concentrate on fabrication of microstructures optimized for wavelengths corresponding to energy slightly below the band gap of GaAs. In particular, the design is optimized for InAs/GaAs quantum dot (QD) solar cells [6]. Numerical optimization and realization of a structured polymer combined with silver back reflector are reported.

2. Experimental

The back reflector structure was simulated using Finite-difference time-domain (FDTD) and Rigorous coupled-wave analysis (RCWA) methods to find the optimum dimensions for absorption near GaAs absorption edge [6]. Our design involved a structure with a period of 3 µm and a height of ~1 µm. Double-side polished semi-insulating GaAs samples were used for fabrication of demonstrators. The front and backside ARCs consisted of a single-layer SiN_x grown by plasma enhanced chemical vapor deposition. The front ARC was optimized to minimize reflection at the air/GaAs interface and the backside ARC was optimized for the GaAs/polymer interface.

   The photonic structures were fabricated by photolithography using a commercial photoresist, SU-8 photoepoxy, which is widely used in electronic industry and which is chemically and mechanically stable and has low absorbance above 400 nm. Two different SU-8 structures were prepared by alternating the photolithography process parameters, such as exposure time and baking temperature. Additionally, the sample with planar SU-8 was used as a reference. On top of the polymer layer, 200 nm silver was deposited using electron beam evaporator. The schematic structures of the samples are presented in Fig.1.
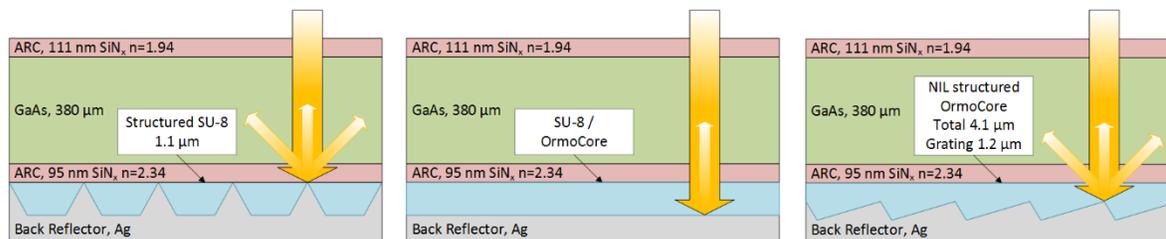

Fig. 1. The schematic drawing with half sphere SU-8 structure (left), with planar layer (middle) and asymmetric triangular grating (right).

In the second approach, the microstructures were fabricated by nanoimprint lithography (NIL). The NIL stamp was fabricated using silicon NIL master with asymmetric triangular grating. The structure was imprinted to OrmoCore (Micro resist technology GmbH) NIL resist and had a period of 3.3 µm and a height of 1.2 µm. The schematic drawings of the test structure and the planar reference structure are presented in Fig. 1.

The specular reflectance (8° angle) of the samples was measured with a PerkinElmer Lambda 1050 spectrophotometer. In addition, the diffuse reflectance was measured by integrating sphere module of the spectrophotometer. To quantify the amount of diffracted light, the spectral diffraction efficiency of one sample was simulated and measured at diffraction orders of m=0, 1, and 2 by variable angle measurement technique.

3. Results

Three SU-8 structures were fabricated: cylinder, half sphere, and planar. The top of the half sphere showed slightly flattened shape, which is presented in the optical profilometer image in Fig. 2. Scanning electron microscopy (SEM) image of the asymmetric triangular grating is also presented in Fig. 2.
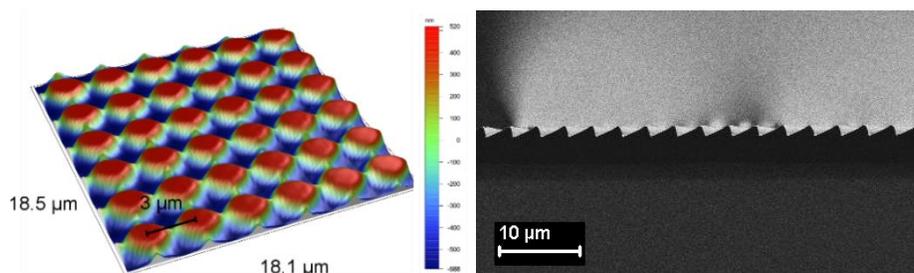

Fig. 2. Optical profilometer image of the half sphere structured SU-8 (left) and SEM image of asymmetric triangular grating (right).

The reflectance measurement of the samples are presented in Fig. 3, where the solid lines represent the diffuse reflectance of the samples. The difference between the diffuse and the specular reflectance shows the amount of diffracted light. According to our observations, the sample with half sphere structure shows higher diffraction behavior when compared to the cylinder one, due to larger amount of slanted surfaces in the half sphere structure. Furthermore, the sample with asymmetric triangular grating showed even higher light diffraction in the QD wavelength range of 900-1100 nm, where the half sphere structure had a local maximum in the specular reflectance. However, the diffuse reflectance of the triangular grating is reduced, which is most likely related to surface plasmon related issues. In future, such effects can be overcome using 3D pyramid structures.

The planar structures used as a reference showed high specular reflectance and high reflectance in integrating sphere measurements, which was expected. This confirms that SU-8 and OrmoCore polymers have rather low absorbance and that the majority of reflectance of the planar reflectors is specular.

Fig. 4 shows the measured and the experimental diffraction efficiency of the half sphere sample. The results show good correlation between the simulation and measurements. Significant power coupling to the first two diffraction orders is observed.

Finally we would like to conclude that the structure and results presented are not limited only for III-V semiconductor solar cells, but also applicable for other types of solar cells by tuning the optimal dimension of the polymer structure to match the required wavelength range.
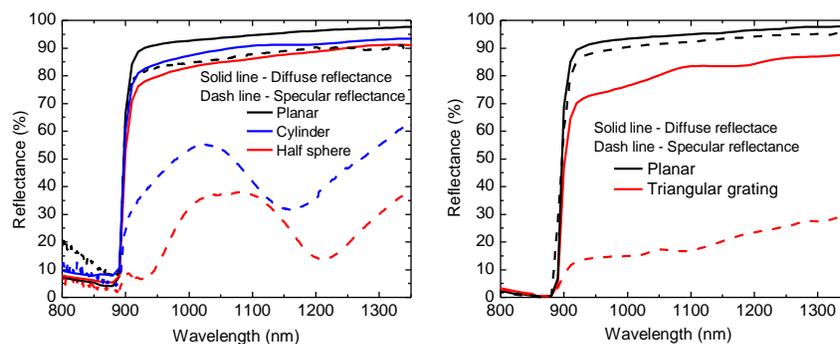

Fig. 3. Diffuse and specular reflectance results of SU-8 gratings with various shapes (left) and Ormocore asymmetric triangular grating (right). The absorption of GaAs is present below the wavelength of 900 nm.
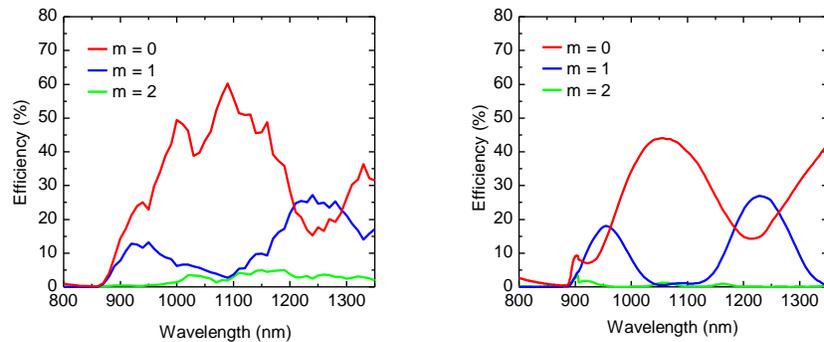
Fig. 4. Simulated (left) and measured (right) diffraction efficiency of the half sphere structured sample.

4. Acknowledgements

5. References

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