# Light management with sinusoidal nanotextures

Klaus Jäger,<sup>1,2,\*</sup> Phillip Manley,<sup>1,2</sup> David Eisenhauer,<sup>1</sup> Philipp Tockhorn,<sup>1</sup> Johannes Sutter,<sup>1</sup> Martin Hammerschmidt,<sup>2</sup> Sven Burger,<sup>2</sup> Steve Albrecht<sup>1</sup> and Christiane Becker<sup>1</sup>

<sup>1</sup> Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner Platz 1, 14019 Berlin, Germany
<sup>2</sup> Zuse Institute Berlin, Takustraβe 7, 14195 Berlin, Germany
\* klaus, jaeger@helmholtz-berlin.de

**Abstract:** Nanoimprint lithography can be used to fabricate sinusoidal nanotextures on a large scale. We present optical and numerical results for sinusoidal nanotextures in two types of solar cells: thin film c-Si and perovskite-silicon tandem solar cells.

**OCIS codes:** (350.6050) Solar energy; (040.5350) Photovoltaic; (000.4430) Numerical approximation and analysis; (310.1210) Antireflection coatings;

#### 1. Introduction

Light management is vital for all high-efficiency solar cell concepts in order to reduce the *reflective losses* and increase the *average light path length* for enhanced absorption in the absorber layer. The latter is especially important for weakly absorbing materials such as silicon in the infrared.

In conventional wafer-based silicon solar cells, pyramids with characteristic dimensions in the micrometer range are used for light management. For thin-film concepts smaller features are required, which happen usually to be comparable to the relevant wavelength of light. This necessitates a wave optical approach, such as *sinusoidal hexagonal nanotextures* illustrated in Fig. 1(a). Due to their smooth nature they can be applied for solar cells types where sharp features would negatively affect the electrical solar cell performance [1].

In this contribution we present two types of solar cells, for which we successfully applied hexagonal sinusoidal nanotextures: (1) *thin-film c-Si solar cells*, where the absorber is fabricated using a *liquid-phase crystallisation* (LPC) process and (2) *perovskite-silicon tandem solar cells*, where sinusoidal nanotextures are used to texture the perovskite top cell. For both applications, we present numerical and experimental results.

## 2. Thin-film c-Si solar cells

Liquid-phase crystallisation (LPC) allows for the fabrication of high-quality c-Si layers on glass with thicknesses up to 40  $\mu$ m [2]. With this technology, a power conversion efficiency (PCE) of 14.2% has been demonstrated [3]. The record cell shows a short-circuit current density of  $J_{\rm sc} = 29.0$  mA/cm<sup>2</sup>, which is low compared to record silicon solar cells. Hence, light management for a higher  $J_{\rm sc}$  is vital to improve the PCE.

Nanoimprint lithography can be used for manufacturing LPC-Si solar cells with sinusoidal nanotextures between the glass superstrate and the LPC-Si layer. These nanotextures not only decrease reflective losses just as effectively as nanopillars, but do not deteriorate the electrical properties, allowing open circuit voltages exceeding 600 mV [4].

We performed optical simulations with the *finite element method* (FEM) on the structure illustrated in Fig. 1(b) [5]. In order to reach good agreement with measured reflectivity spectra, the reflection at the glass-air interface had to be corrected with a scattering matrix approach [6], as shown in Fig. 1(c).

### 3. Perovskite-silicon tandem solar cells

Multi-junction solar cells are the most promising route to surpass the 29.4% PCE limit for c-Si solar cells [7]—and indeed recently a monolithic perovskite-silicon solar cell with 27.3% PCE was presented [8], which is higher than the c-Si record of 26.7% [9].

We performed numerical simulations for perovskite-Si solar cells with a 160 µm thick c-Si absorber, illustrated in Fig. 1(d). We assumed perfect Lambertian light trapping at the rear side of the bottom cell [10]. As shown in Fig. 1(e). with the best sinusoidal texture (500 nm period and peak-to-valley height), the reflective losses could be reduced from 5.5 mA/cm<sup>2</sup> to 2.8 mA/cm<sup>2</sup> with respect to a device with a planar perovskite top cell.

Figure 1(f) shows an SEM image of a spin-coated perovskite layer on a sinusoidally textured substrate. This proves that our sinusoidal nanotextures are compatible with spin-coating processes [10].

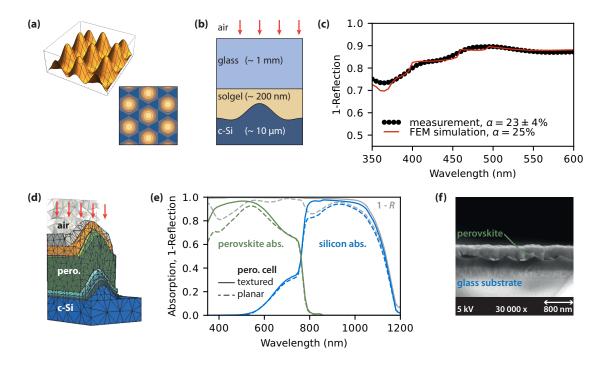


Fig. 1. (a) Illustrating sinusoidal hexagonal textures. (b) A nanotexture between glass and c-Si, as in LPC-Si solar cells. (c) Simulation results and measurements of 1-R for 500 nm period; a denotes the aspect ratio [6]. (d) FEM grid for a nanotextured perovskite-Si cell [10]. (e) Simulated absorption spectra and 1-R for cells with a planar perovskite front side or a textured perovskite front side [10]. We assumed Lambertian scattering at the rear side of Si. (f) An SEM picture of a spin-coated perovskite layer on a sinusoidally nanotextured substrate.

## 4. Conclusions and outlook

Sinusoidal nanotextures are well suited for light management in LPC-Si and perovskite-Si tandem solar cells. Because of their smooth nature they maintain electrical performance while providing excellent light trapping. In a next step we plan to build fully-textured perovskite-silicon solar cells.

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