# Large area interference lithography as mastering technique to pattern silicon-based tandem solar cells

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In this presentation, we will introduce our capabilities in the field of mastering using interference lithography and will discuss the business case of silicon-based tandem solar cells as a potential field of application.

An efficiency increase of approx. 0.6 % per year can be observed in silicon PV industry in the past [1] (Fig.1, left). Yet, there will be an end to these improvements as physics limits the efficiency of single junction silicon solar cells to 29.4 % [2]. One way to circumvent this dead end is based on the well-known method of stacking semiconductors of higher bandgaps preferably on silicon. This trend can be seen in research and is already listed in the technology roadmap of the PV industry, where projections already predict a production of such cells from 2023 on [3]. Until 2030 the PV market will grow from currently ~ 100 $GW_{peak}$ to over 1000 $GW_{peak}$ annual production [4]. With a price of approx. 10 cent per $W_{peak}$ this will be a total market volume in the range of ~ 100 billion US $.

The current record for a two terminal silicon-based tandem device incorporates a photonic rear side structure, raising the cell efficiency from 31.4 % to 33.3 % [5]. This photonic rear is based on a master structure realized via interference lithography [6], which is subsequently replicated via Roller-NIL [7] (Fig. 2).

In interference lithography a laser beam is split into two or more beams, which then are filtered, expanded and superimposed on a photoresist coated sample. The resulting interference pattern is applied to expose photoresists, leading to a surface relief after the wet chemical development. We use an argon-ion laser emitting at 363.8 nm for this process. By varying the setup, this technology can be applied to realize patterns with periods ranging from 200 nm up to 100 µm arranged in different symmetries (e.g. linear, crossed or hexagonal patterns) and also to realize (tailored) diffuser structures. Also modifications of the structure profile are possible (e.g. prismatic or continuous spherical/aspherical shapes). The big strength of this technology is the possibility to realize seamless micro and nanostructures on very large areas. The largest sample size patterned in our labs up two now is 1.2 x 1.2 m² (Fig.2, right). Besides PV, potential fields of application for interference lithography are photonic structures for LED´s (e.g. light out-coupling, directed emission), displays (e.g. polarization optical elements) or sensing (e.g. plasmonics or resonant-waveguide gratings).

Reference:

[1] M. Hermle, ETIP PV Manufacturing Conference 2017
[2] A. Richter et al. “Reassessment of the limiting efficiency for crystalline silicon solar cells,” IEEE Journal of Photovoltaics 3, 1184–1191 (2013).
[3] ITRPV, International Technology Roadmap for Photovoltaic. 2018 Results 10th Edition, 2019.
[4] F. Creutzig et al. “The underestimated potential of solar energy to mitigate climate change,” Nat. Energy 2, 17140 (2017).
[5] R. Cariou, et al. “III–V-on-silicon solar cells reaching 33% photoconversion efficiency in two-terminal configuration,” Nature Energy 17, 183 (2018).
[6] A. J. Wolf et al. “Origination of nano- and microstructures on large areas by interference lithography,” Microelectron Eng 98, 293–296 (2012).
[7] H. Hauser et al. “Honeycomb texturing of Silicon via nanoimprint lithography for solar cell applications,” IEEE Journal of Photovoltaics 2, 114–122 (2012).

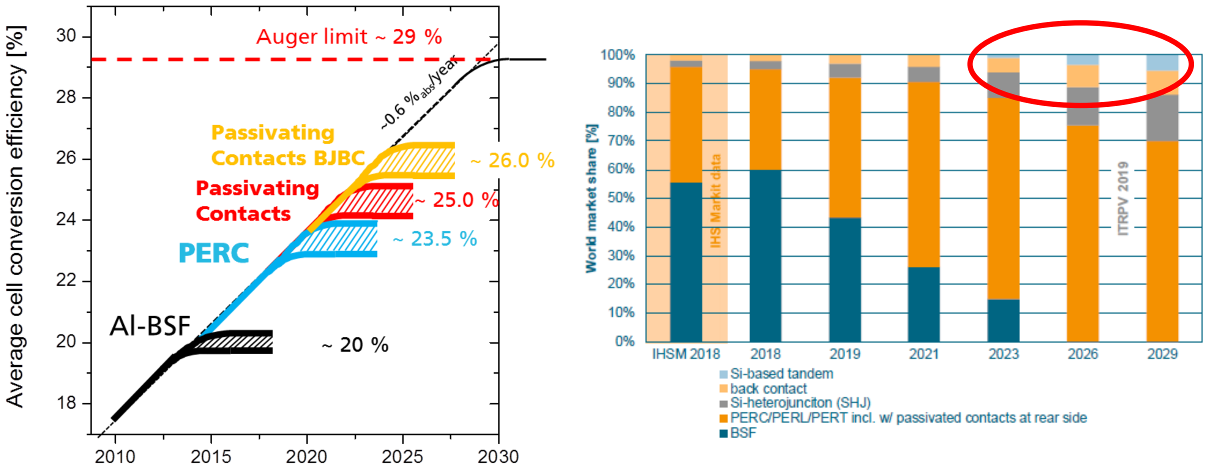

**Figure 1.** Left: Efficiency increase of ~ 0.6 %/year based on data from industrial fabrication for different silicon solar cell architectures (adapted from Ref. [1]). The intrinsic efficiency limit around 29 % is also sketched. Right: Technology roadmap of the PV industry showing the emergence of silicon based tandem solar cells in 2023 (red circle) [3].

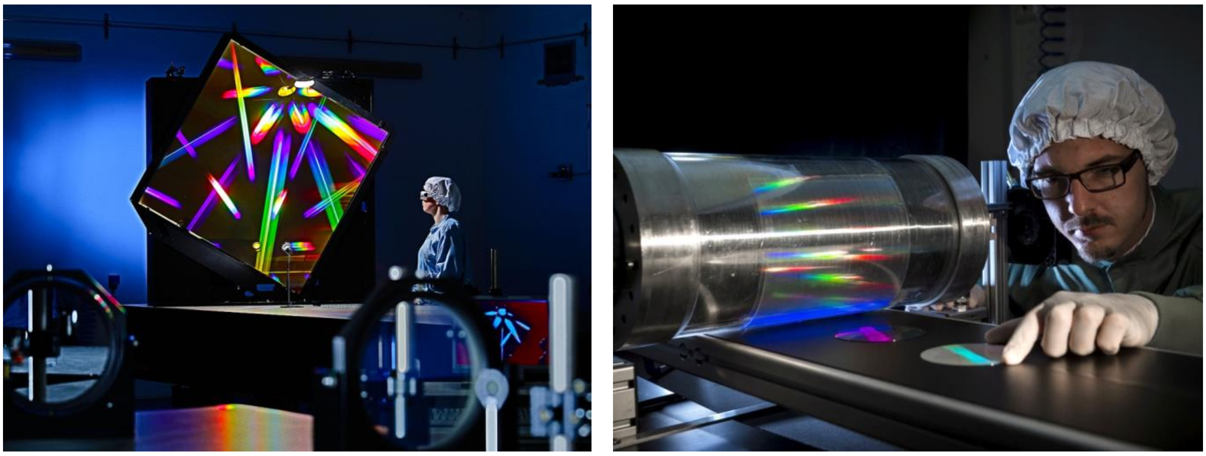

**Figure 2.** Left: Photograph of the largest seamlessly patterned sample at Fraunhofer ISE up to now. A hexagonal grating with a period of 1 µm was realized on 1.2 x 1.2 m². Right: Photograph of the Roller-NIL developed at Fraunhofer ISE. This tool has the functionality of a roll-to-plate tool with a UV-light source realized within a quartz roller. Thus it can be applied to pattern UV-curable materials on opaque and stiff substrates.