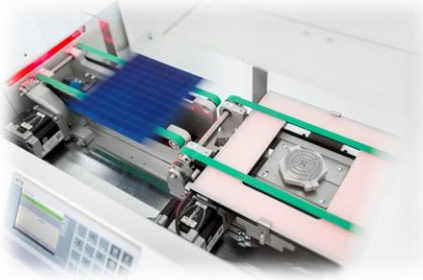
PEarl

„PERC meets self-aligned selective emitter technologies based on inkjet printing and silver less plating”

Dr.-Ing. Roman Keding, Raphael Efinger
Fraunhofer Institute for Solar Energy Systems ISE
Heidenhofstr. 2, 79110 Freiburg, Germany
roman.keding@ise.fraunhofer.de,
+49(0)761/4588-582

Agenda

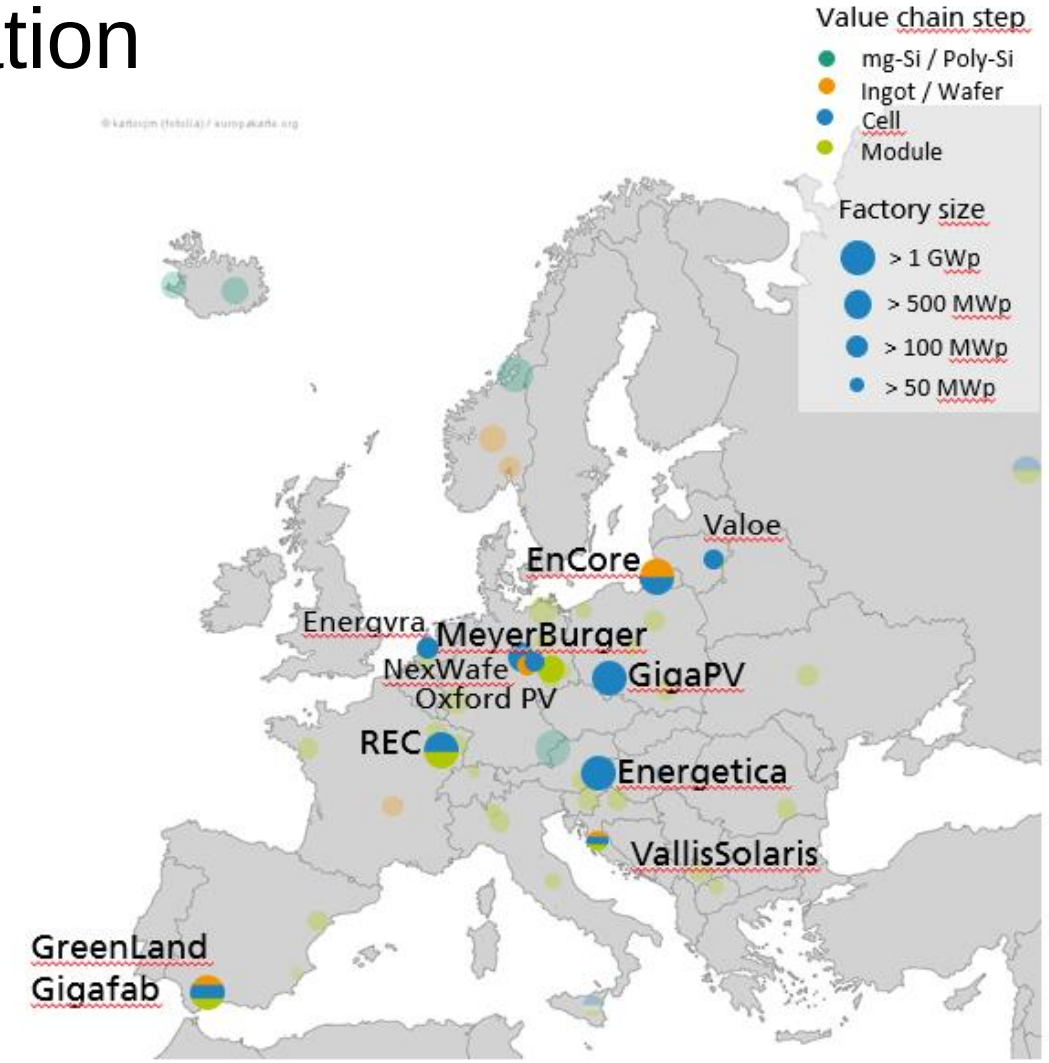
- Motivation
- Approach
- Results and Outlook
- Dissemination and exploitation
- Self-reflection on PEarl



Motivation

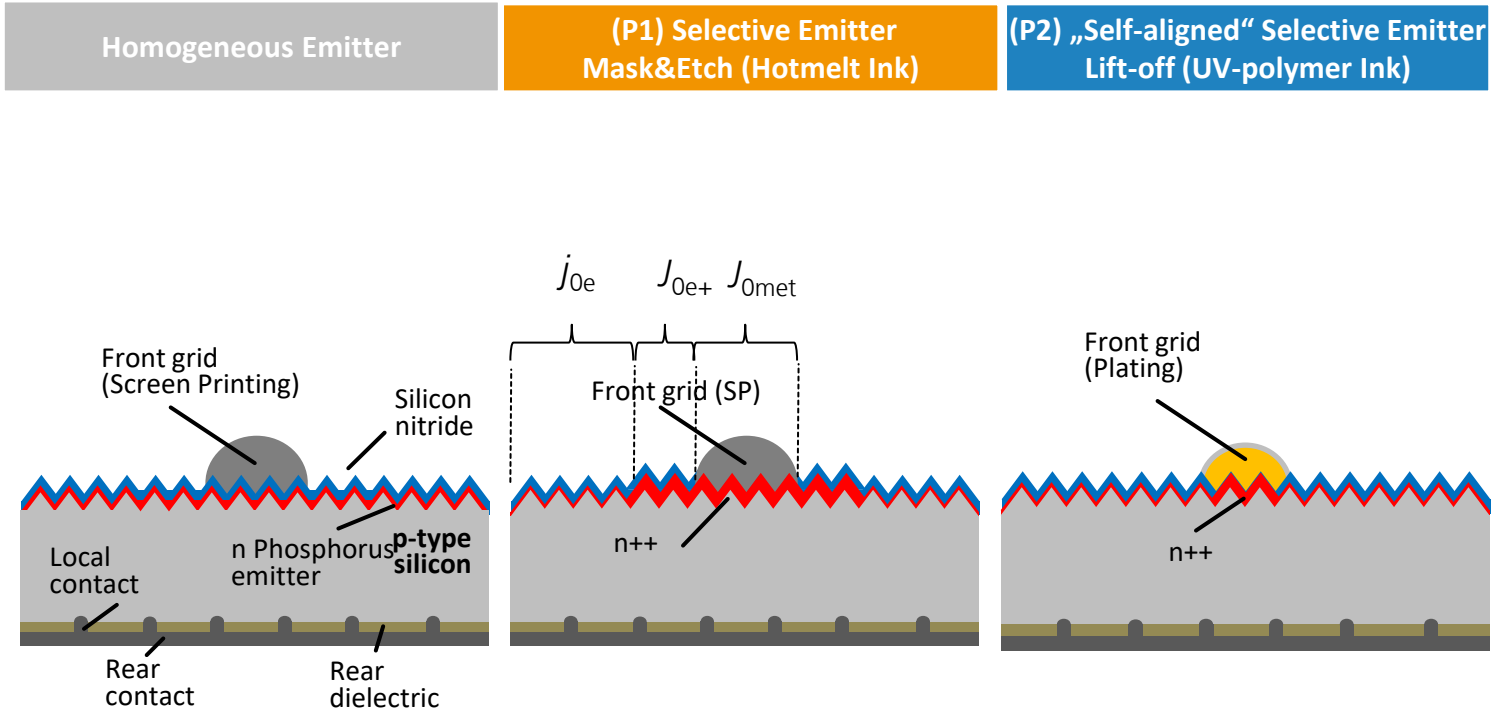
- Renaissance of PV-Manufacturing in Europe
- Innovative cells and technologies
- Differentiation against available value chains in Asia

- Industrial interest for developing inks with high chemical and thermal stability



Approach

- PERC solar cells with selective emitter
- The PEarl technology
  - High efficiency
  - Low cost (negligible Ag)
  - Innovative materials
  - Digital printing and plating
  - Self-aligned patterning
- PV-TEC pilot-lines

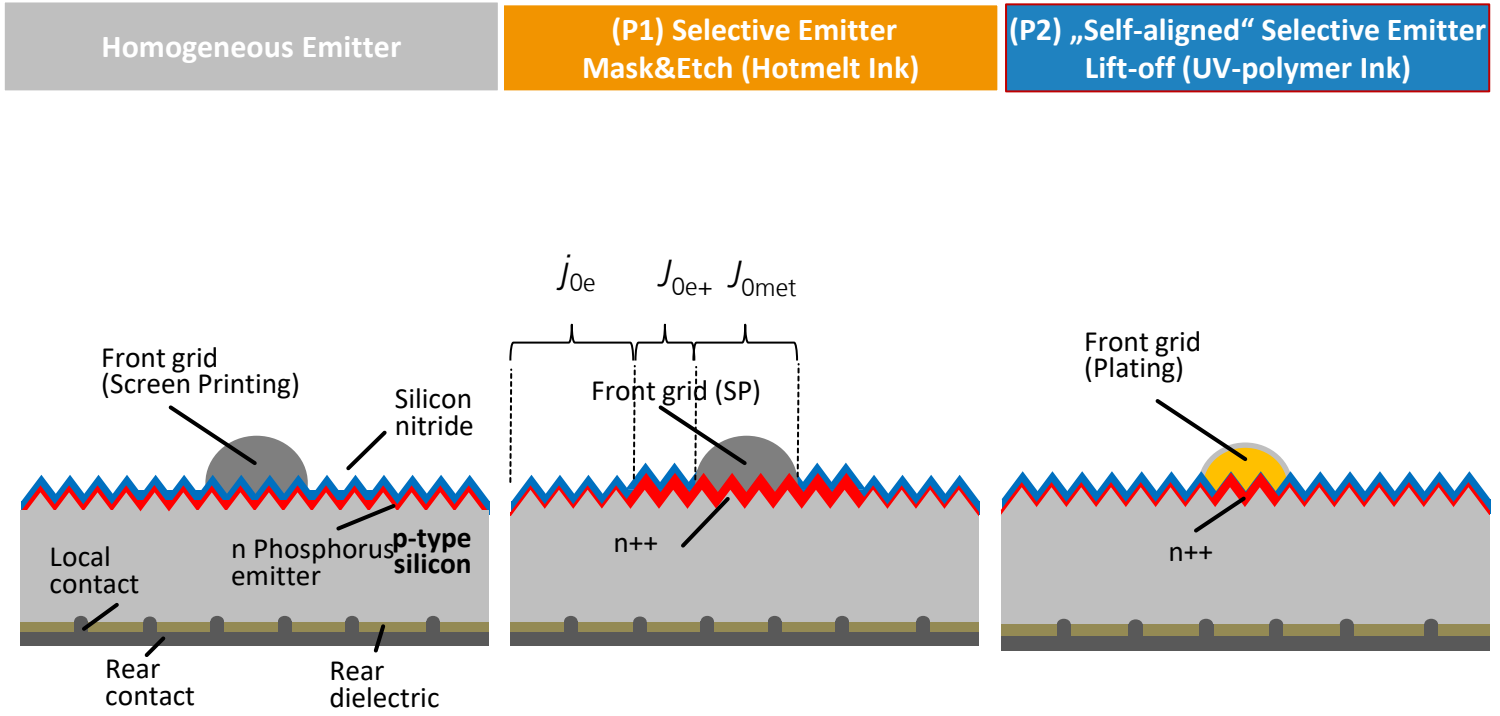


PERC Passivated Emitter and Rear Cell
PV-TEC Photovoltaic Technology Evaluation Center

R. Keding et al., SNEC 2019
R. Efinger et al., EUPVSEC 2020

Approach

- PERC solar cells with selective emitter
- The PEarl technology
  - High efficiency
  - Low cost (negligible Ag)
  - Innovative materials
  - Digital printing and plating
  - Self-aligned patterning
- PV-TEC pilot-lines



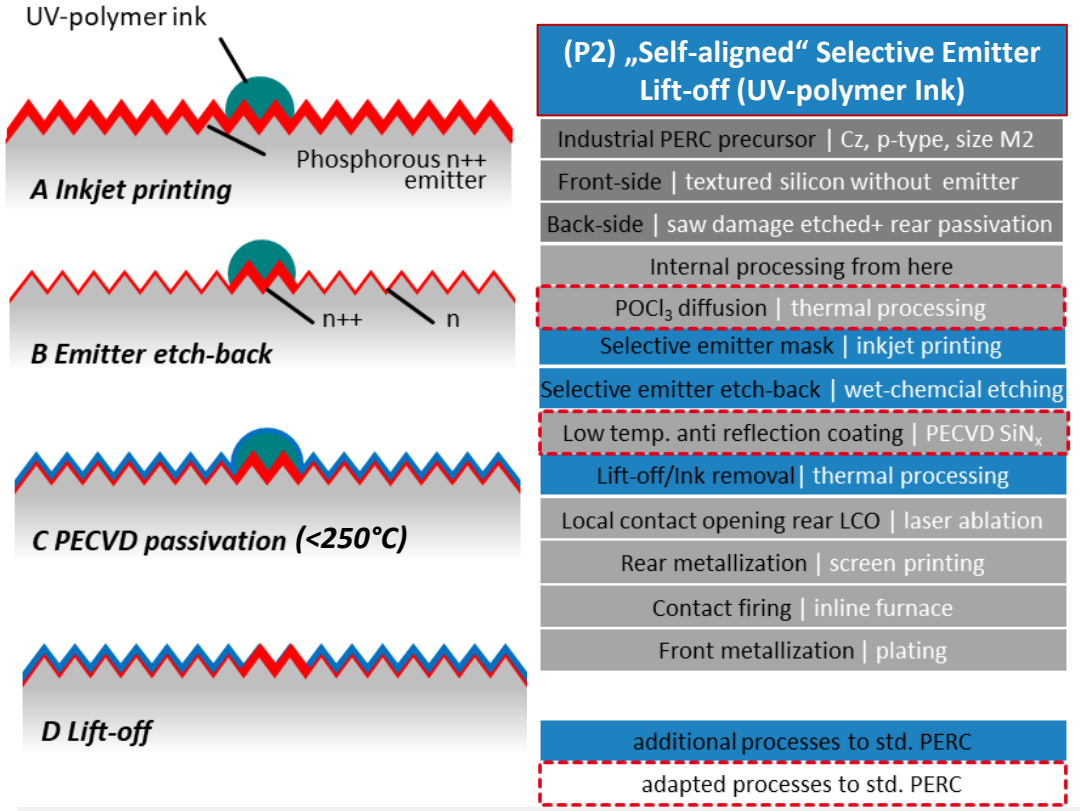
PERC Passivated Emitter and Rear Cell
PV-TEC Photovoltaic Technology Evaluation Center

R. Keding et al., SNEC 2019
R. Efinger et al., EUPVSEC 2020

Approach

- PERC solar cells with selective emitter
- The PEarl technology
  - High efficiency
  - Low cost (negligible Ag)
  - Innovative materials
  - Digital printing and plating
  - Self-aligned patterning
- PV-TEC pilot-lines

PERC Passivated Emitter and Rear Cell
PV-TEC Photovoltaic Technology Evaluation Center

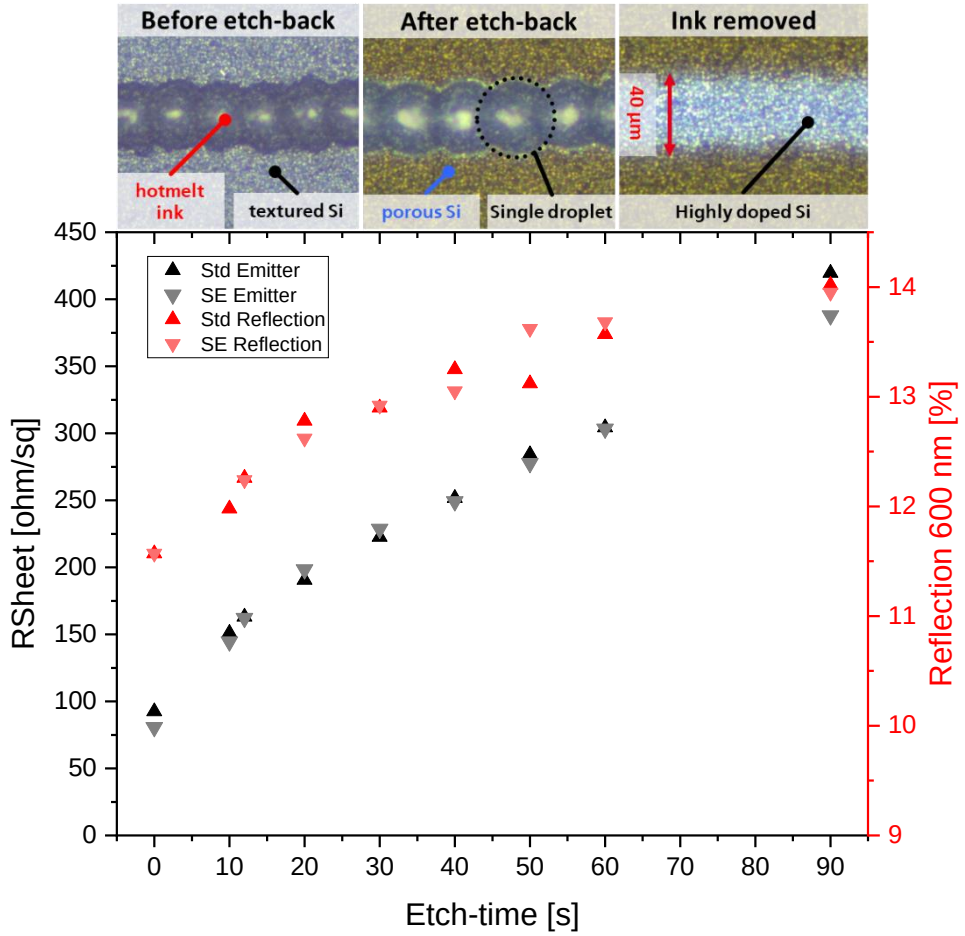


Left: Core processes of the self-aligned emitter route.
Right: Process flow of this study based on industrial PERC precursors

Results: selective etching of silicon

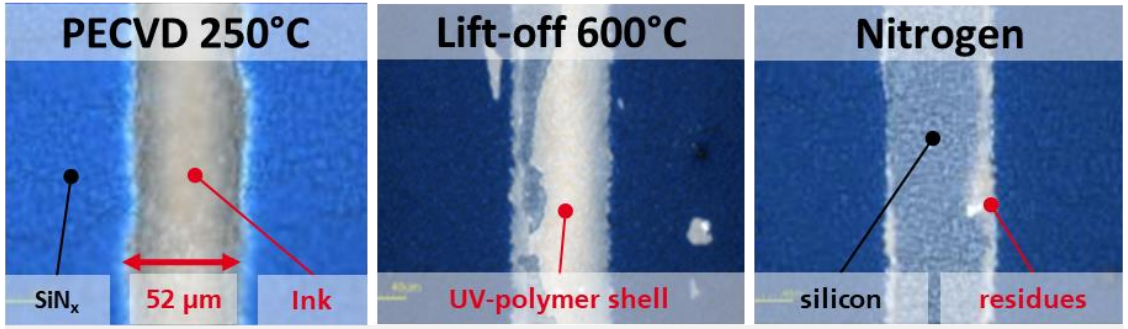
- HNO_3 based Si-etching
  - 80 Ω/sq → 144 Ω/sq
  - Short etch-times of 10-15 s
- Perfect congruency of masked and etched regions
- Compatibility to hotmelt and UV-polymer inks
- Processes compatible to mass production tools

R. Efinger et al., EUPVSEC 2020

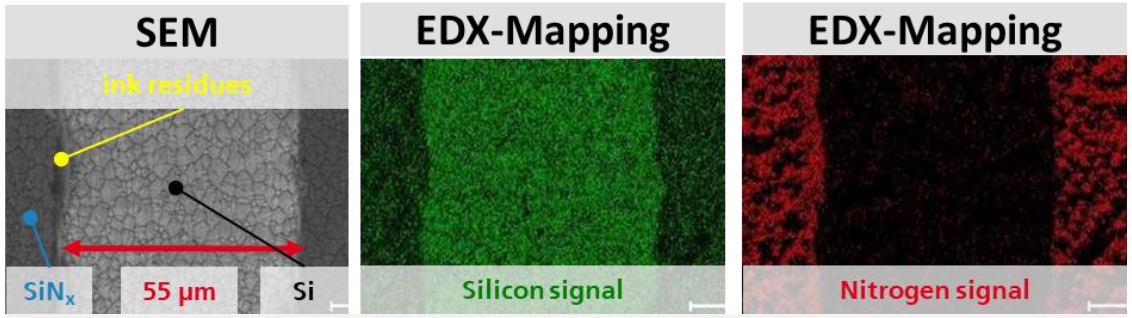


Results: lift-off patterning of SiN_x

- Innovative lift-off mechanism
  - Specific low-temperature SiN_x
  - Thermally triggered at 600°C
    → Sudden evaporation of wax
    → Degradation of UV-polymer
  - Residues (UV-polymer shell) removed by high pressure nitrogen gun
- EDX → No residues of passivation (SiN_x) detected



Microscopic images after PECVD, Lift-off and post-treatment with nitrogen



SEM/EDX-measurements at the same position of a sample after lift-off

B. Kafle et al., EUPVSEC 2020
R. Efinger et al., EUPVSEC 2020

SEM Scanning Electron Microscopy
EDX Energy-dispersive X-ray spectroscopy

Results: process integration PERC

- Successful PERC integration
- Mask&etch enables + 0.2%$_{abs}$
- Lift-off: promising PoC
  - Efficiency η = 19.7%
  - High fill factor FF (similar to Laser-reference, process homogeneity)
- Potentials for optimization
  - Decrease metal & contact area
  - Improve ghost plating

R. Efinger et al., EUPVSEC 2020

PoC Proof-of-Concept

(P1) Selective Emitter Mask&Etch (Hotmelt Ink)		(P2) „Self-aligned“ Selective Emitter Lift-off (UV-polymer Ink)	
1 Reference HE | SP30	2 SE100 | SP30	3 Reference HE | PL22	4 SE55 | PL60
Homogeneous emitter 95 Ω/sq	Selective emitter 80 Ω/sq / 144 Ω/sq	Homogeneous emitter 95 Ω/sq	Selective emitter 95 Ω/sq / 151 Ω/sq
	Hotmelt 100 µm	Laser Contact Opening 15 µm	Hybrid Ink 55 µm
Standard Passivation			Low Temperature 250°C
Screen Printing 30 µm/120 fingers		Plating 22 µm/115 fingers	Plating 60 µm/115 fingers

Group overview of the process integration experiment including a conventional mask&etch and the self-aligned emitter approach

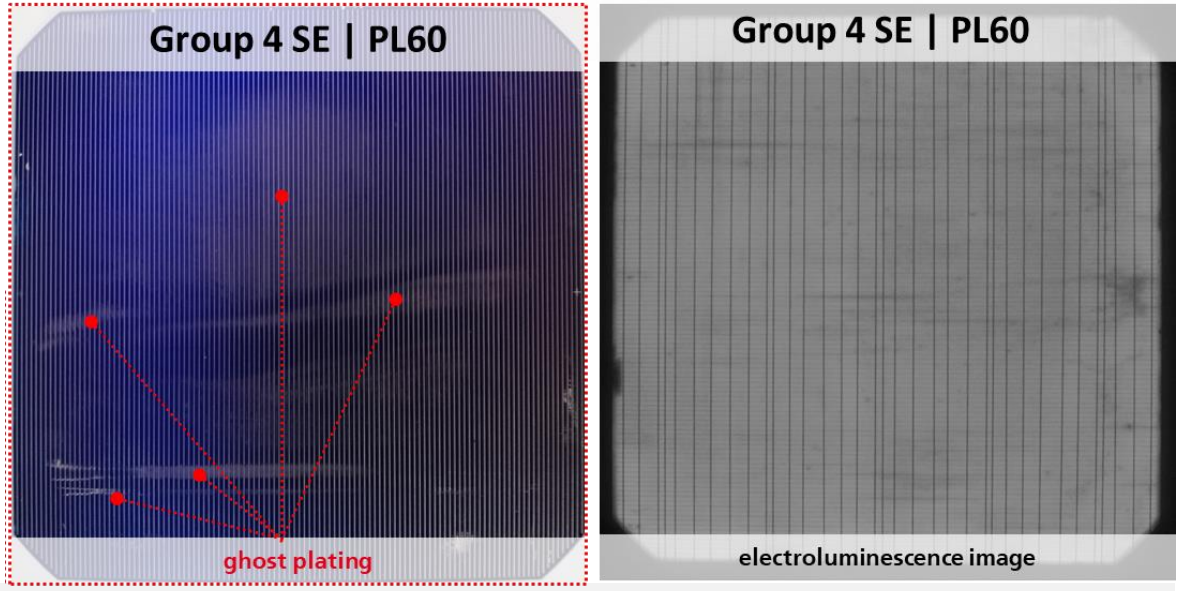
Group	η [%]	V_{OC} [mV]	J_{SC} [mA/cm²]	*FF* [%]
1 Ref. HE | SP30	21.38	665.1	40.0	80.0
2 SE100 | SP30	21.54	670.8	40.1	80.1
3 Ref. HE | PL22	21.29	661.6	40.1	80.2
4 SE55 | PL60	**19.68**	**638.8**	**38.6**	**79.9**

Parameters from STC current-voltage characterization measured using PCBtouch for busbarsless cells.

Results: process integration PERC

- Successful PERC integration
- Mask&etch enables + 0.2%$_{abs}$
- Lift-off: promising PoC
  - Efficiency η = 19.7%
  - High fill factor FF (similar to Laser-reference, process homogeneity)
- Potentials for optimization
  - Decrease metal & contact area
  - Improve ghost plating

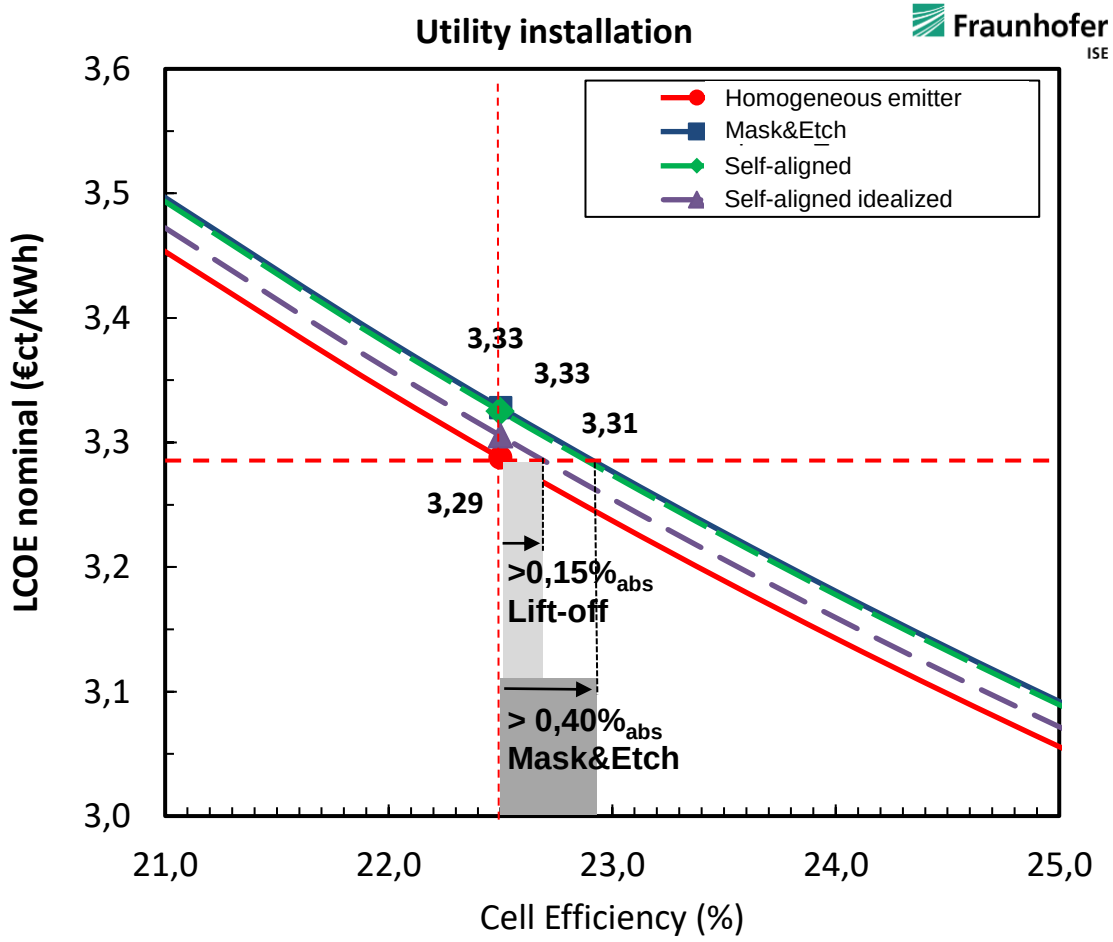
R. Efinger et al., EUPVSEC 2020



Left: Camera image of fully plated wafer
Right: Homogeneous electroluminesence response of fully plated wafer

Results: techno-economical assessment

- Cost parity with standard PERC at η improvement of 0,15%$_{abs}$
- Lift-off enables superior cost-saving potential



R. Efinger et al., EUPVSEC 2020

Outlook

- ***Further reduction of printed line-width (metal, x_{min} < 15 µm)***
  - Switching to new industrial print-heads with low droplet volume
- ***Improvement of low temperature passivation scheme (improve V_{OC})***
  - Evaluation of further deposition techniques (ALD)
- ***Transfer of PEarl approaches to TOPCon (ISE's record cell)***
  - Patterning of poly-Si and/or c-Si (*p*-type)
- ***Attract Users for PEarl technology***

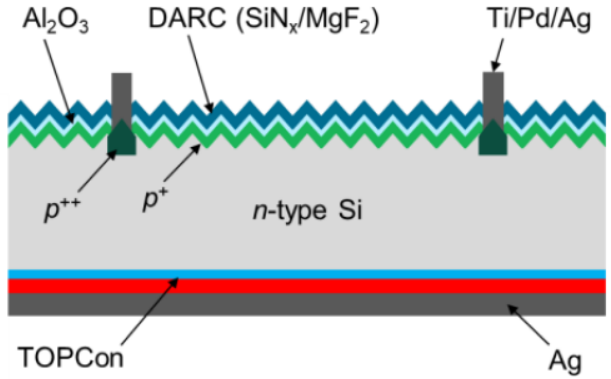


Figure 1: Schematic cross-section of the *n*-type Si solar cell with a front-side boron-doped emitter and full-area passivating rear contact (TOPCon).

Table 1: *I-V* parameters and *PFF* measured at the best cell under STC (designated area: 2×2 cm^2).

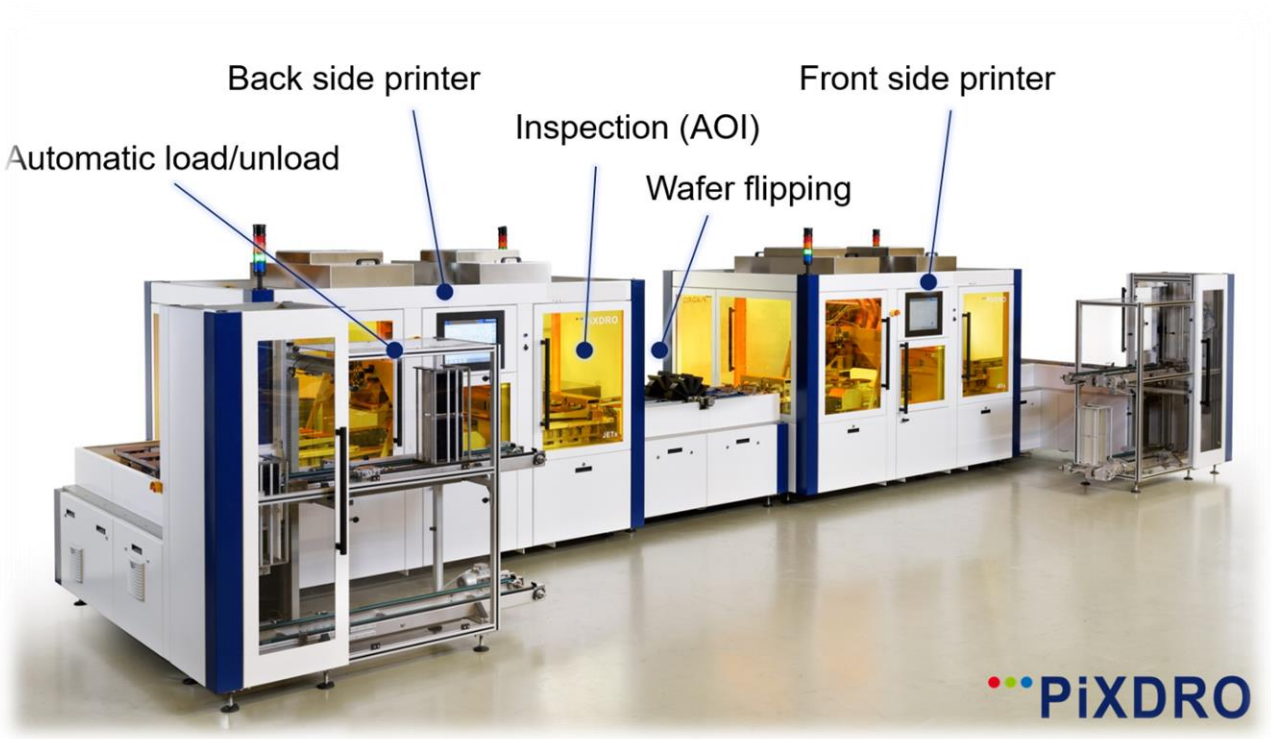
V_{OC} (mV)	J_{SC} (mA/cm^2)	*FF* (%)	*PFF* (%)	η (%)
724	42.9	83.1	85.6	25.8*

*Independently confirmed by Fraunhofer ISE CalLab

A. Richter et al., EUPVSEC 2019

Dissemination and exploitation

- Follow-up projects
- Education of engineers and scientists
- Promotion of PEarl at exhibitions and conferences
- Technology transfers and licensing
- Further sales of machines and materials at SÜSS and SunChemical (PV and Semicon)



Self-reflection on PEarl

- The transnational set-up is valuable, because
  - Strengthens research and industry network of europe (more heads, more expertise)
  - Intercultural exchange (mixtures of different mindsets enables new/innovative solutions)

  … it brings European ideas and solutions alive

- Critical factors and lessons learned
  - Fire accident at Fraunhofer ISE
  - Partners from PV-manufacturing would be really appreciated (e.g. for validation)

Acknowledgement

The project PEarl (020ESOLARERANET5-26) is supported under the umbrella of SOLAR-ERA.NET Cofund by Project Management Jülich as project agency for the Federal Ministry of Economic Affairs and Energy (BMWi) of Germany, RVO (Directorate Energy Innovation) of the Netherlands, and Innovative UK of the United Kingdom. SOLAR-ERA.NET is supported by the European Commission within the EU Framework Programme for Research and Innovation HORIZON 2020 (Cofund ERA-NET Action, N° 786483)