PROGRESS WITH ROTARY SCREEN PRINTED FINE LINE METALLIZATION FOR SILICON HETEROJUNCTION SOLAR CELLS

40 YEARS
FRAUNHOFER ISE
#CreatingTheEnergyFuture

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Rotary Printing for Solar Cell Metallization

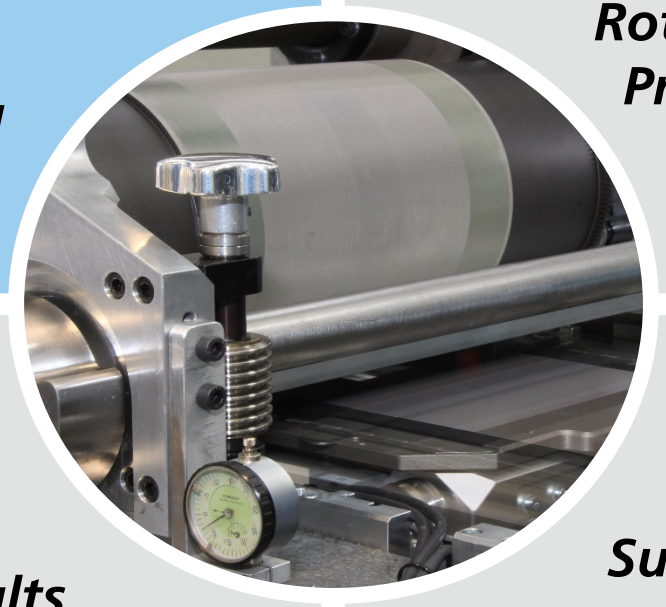
Agenda

1. Background & Motivation

Background and Motivation

2. Technology

Rotary Screen Printing Technology



3. Experiment

Experimental Setup and Results

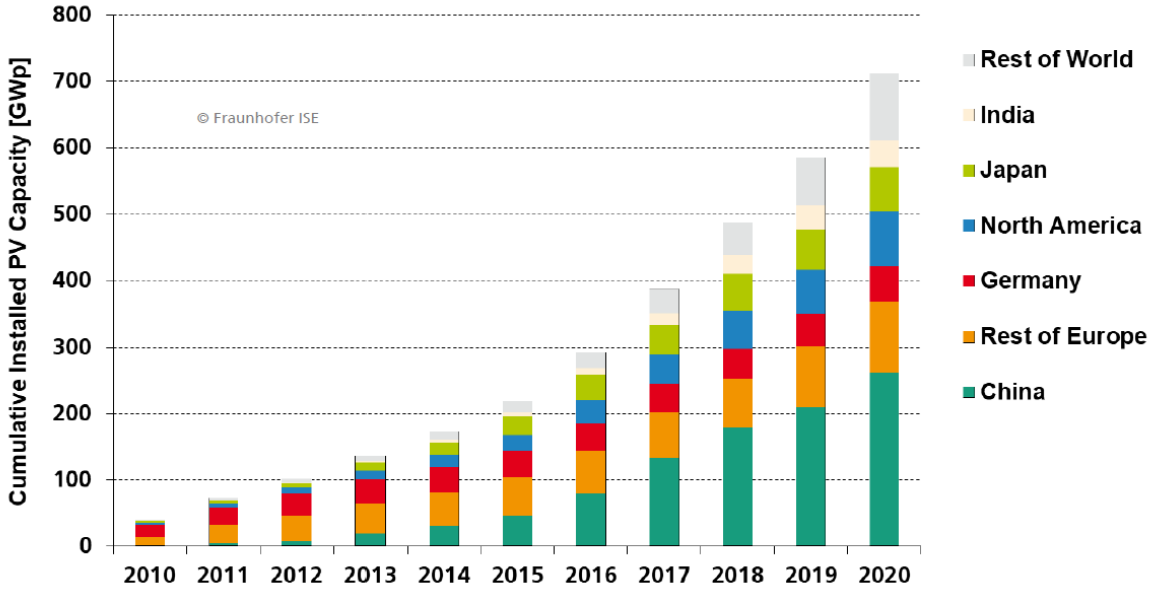
4. Summary and Outlook

Summary of Results and Outlook

Rotary Printing for Solar Cell Metallization

Background and Motivation

- Globally installed PV capacity rapidly approaches **terawatt-scale**
- Decrease costs of cell and module production



Cumulative installed global PV capacity from 2010 to 2020 (Source: PSE Projects GmbH, taken from Fraunhofer ISE Photovoltaics Reports 2021)

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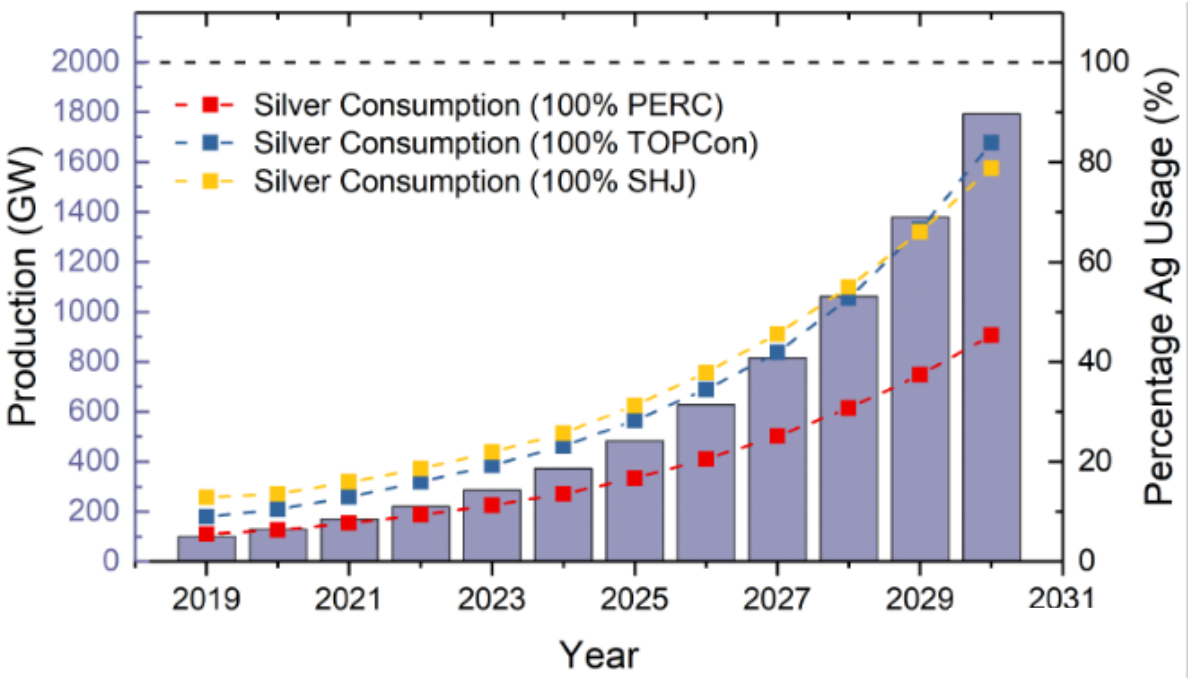
Rotary Printing for Solar Cell Metallization

Background and Motivation

- Globally installed PV capacity rapidly approaches **terawatt-scale**
- Decrease costs of cell and module production
  - Reduction of critical ressources:
    → Current Ag consumption would require up to **90%** of global production in 2030[1]



Predicted increase of the required global annual silver production of the PV industry until 2031 for different cell technologies [1]

[1] Hallam, B. et al., 11th SiliconPV (2021)

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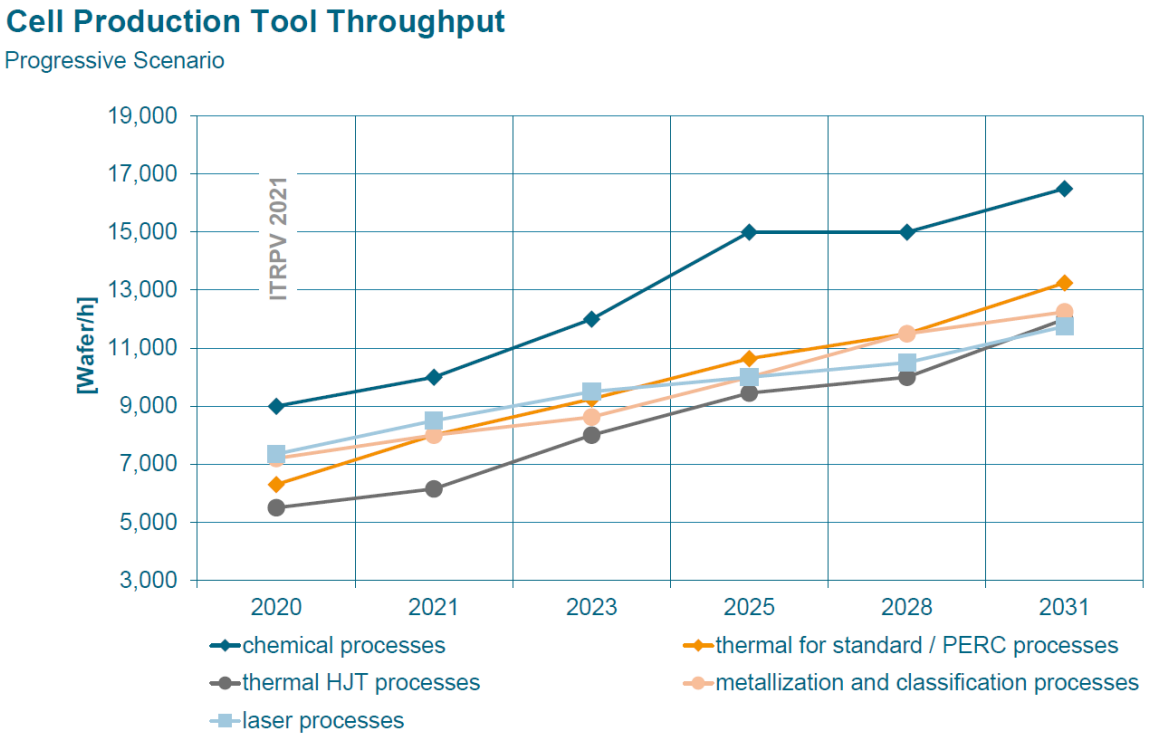
Rotary Printing for Solar Cell Metallization
Background and Motivation

- Globally installed PV capacity rapidly approaches **terawatt-scale**
- Decrease costs of cell and module production
  - Reduction of critical ressources:
    → Current Ag consumption would require up to **90%** of global production in 2030
  - Substantial increase of throughput required
    → ITRPV Prediction for Metallization & Classification: ~ **10.000 Wafer/h** in 2025[1]



Actual forecast of the International Technology Roadmap for Photovoltaics (ITRPV) regarding the expected throughput of PV production lines[2]

[1] International Technology Roadmap for Photovoltaic (ITRPV): 2021 Results. 12th Ed. (2021).

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Rotary Printing for Solar Cell Metallization

Background and Motivation

- Globally installed PV capacity rapidly approaches **terawatt-scale**
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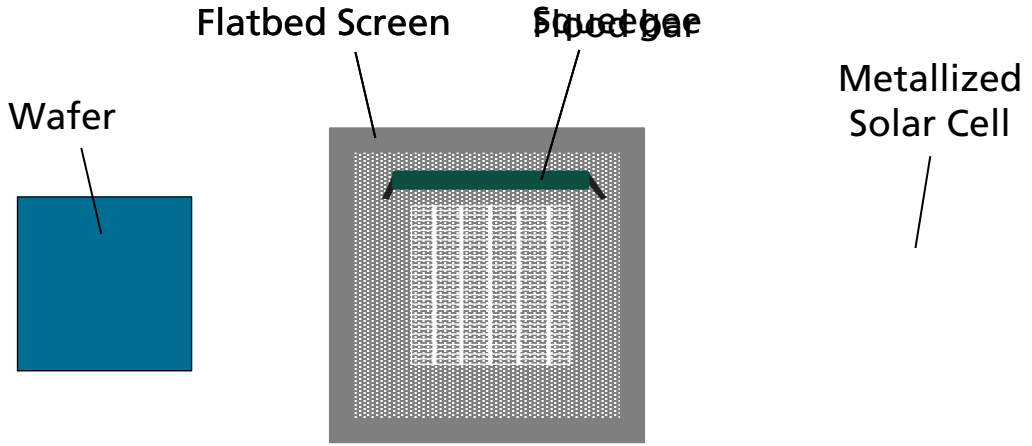
    → Current Ag consumption would require up to **90%** of global production in 2030
  - Substantial increase of throughput required
    → ITRPV Prediction for Metallization & Classification: ~ **10.000 Wafer/h** in 2025[1]
  - Modern flatbed screen printing lines
    Cycle time **t ≈ 1 s**
    → Further reduction difficult due to technical limitations (stop-and-go modus)



[1] International Technology Roadmap for Photovoltaic (ITRPV): 2021 Results. 12th Ed. (2021).

Rotary Printing for Solar Cell Metallization
Challenge

The Challenge:
»Reduce silver, boost production throughput but maintain the same quality level«

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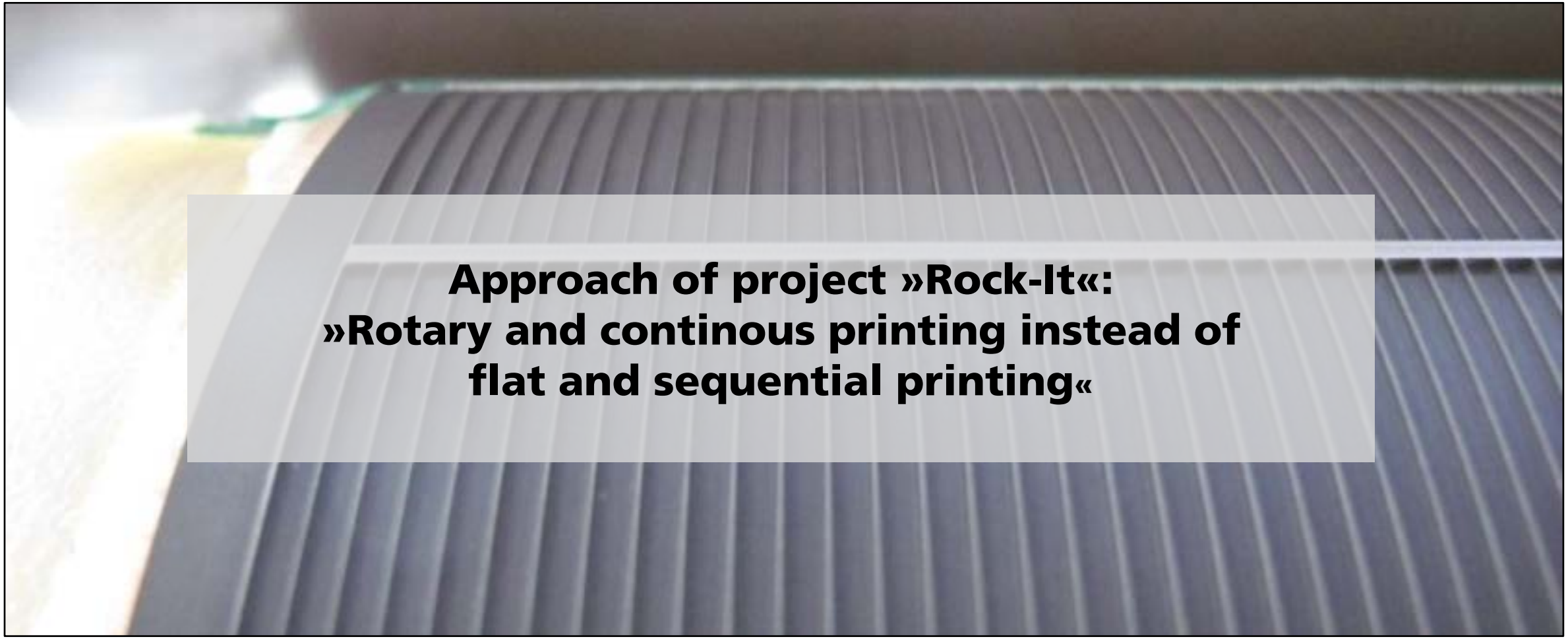
Rotary Printing for Solar Cell Metallization
»Rock-Star« Approach



Approach of project »Rock-It«:
»Rotary and continous printing instead of flat and sequential printing«

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Rotary Printing for Solar Cell Metallization

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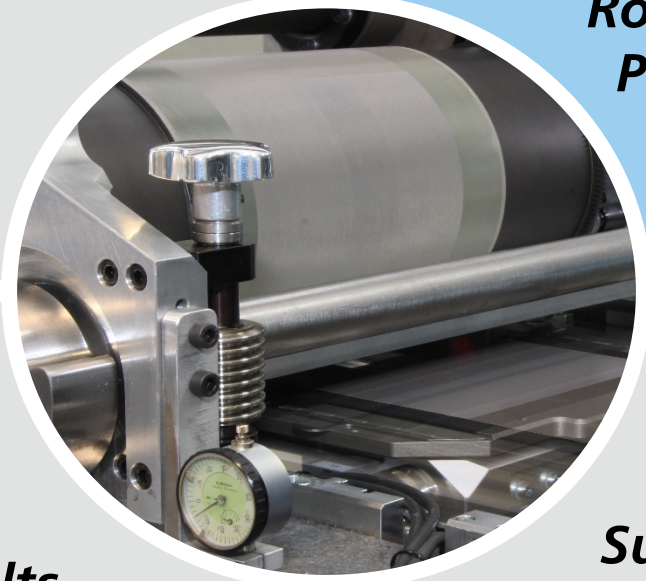

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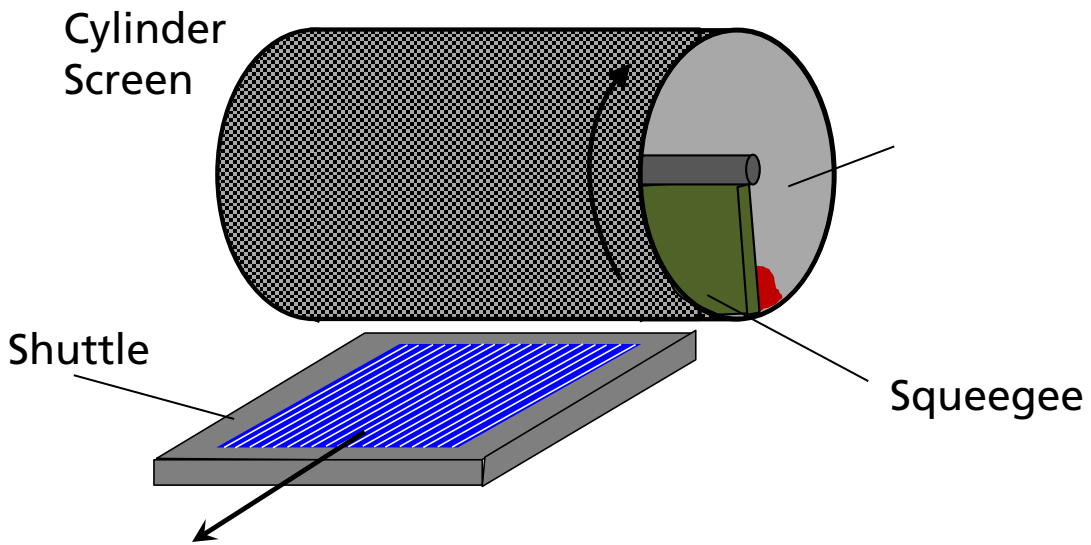
Rotary Printing for Solar Cell Metallization

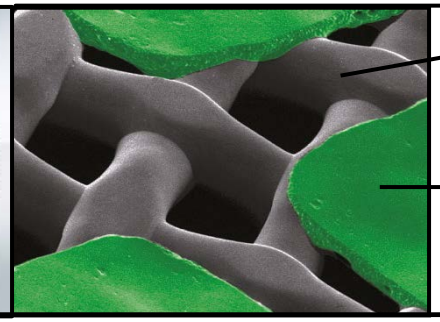
Technical Background – Rotary Screen Printing Technology

- Cylinder-shaped screens
- Mounting of flat screen with gear rings
- Stainless steel meshes: ~64 – 400 wires/inch

Rotary Screen Printing:



Source: Gallus Ferd. Rüesch AG



Open mesh
→ Printing

Emulsion
→ Non-printing

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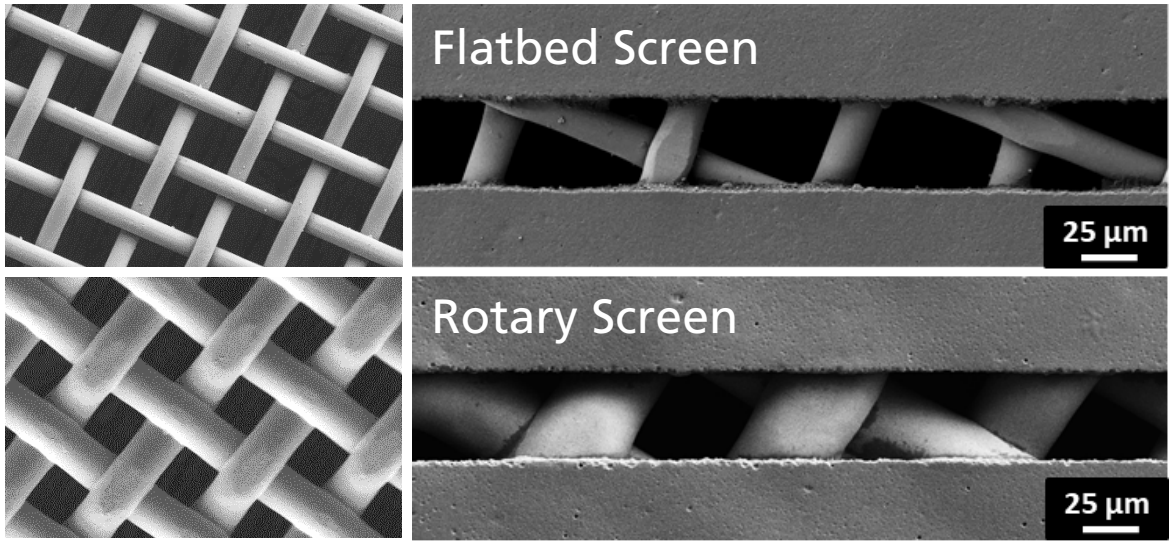
Rotary Printing for Solar Cell Metallization

Technical Background – Rotary Screen Printing Technology

- Cylinder-shaped screens
- Mounting of flat screen with gear rings
- Stainless steel meshes: ~64 – 400 wires/inch
- Fine line channels below 30 µm can be realized on rotary screens
- Wire thickness by factor 2-3 thicker than fineline flatbed screens
  → reduced paste transfer
  → effect on finger geometry



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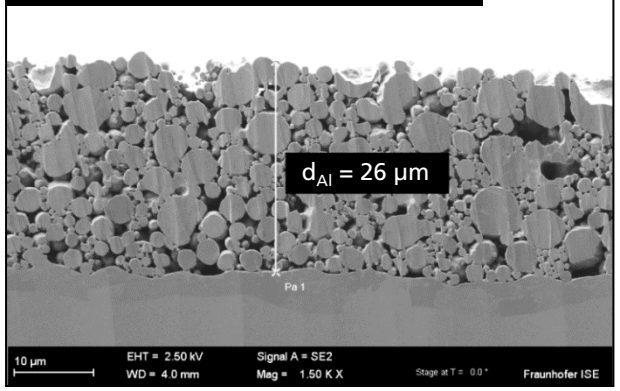
Rotary Printing for Solar Cell Metallization

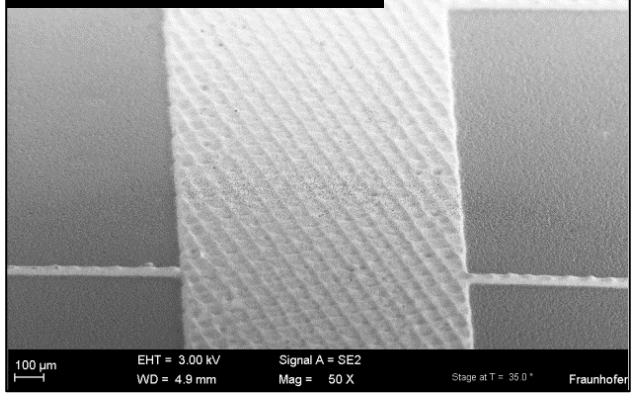
Technical Background – Rotary Screen Printing Technology

- Feasibility for solar cell metallization successfully demonstrated:
  - Rear side metallization of Cz-Si PERC solar[1]
  - Front side grid for Cz-Si PERC with fine line fingers down to $w_f \approx$ 40 µm[2]

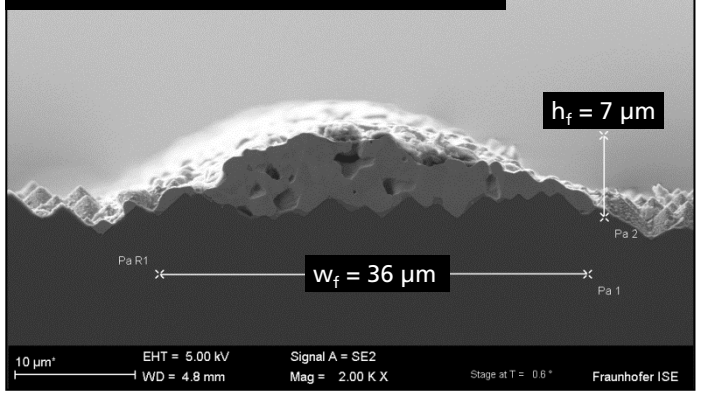
RSP printed PERC Al rear side

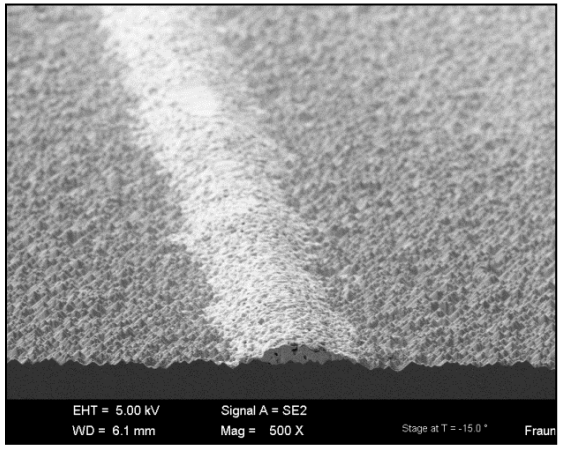


RSP printed Ag Busbar



RSP printed front side contacts





[1] Lorenz et al., Energy Proc. 124 (2017)
[2] Lorenz et al., PhD Thesis (2018)

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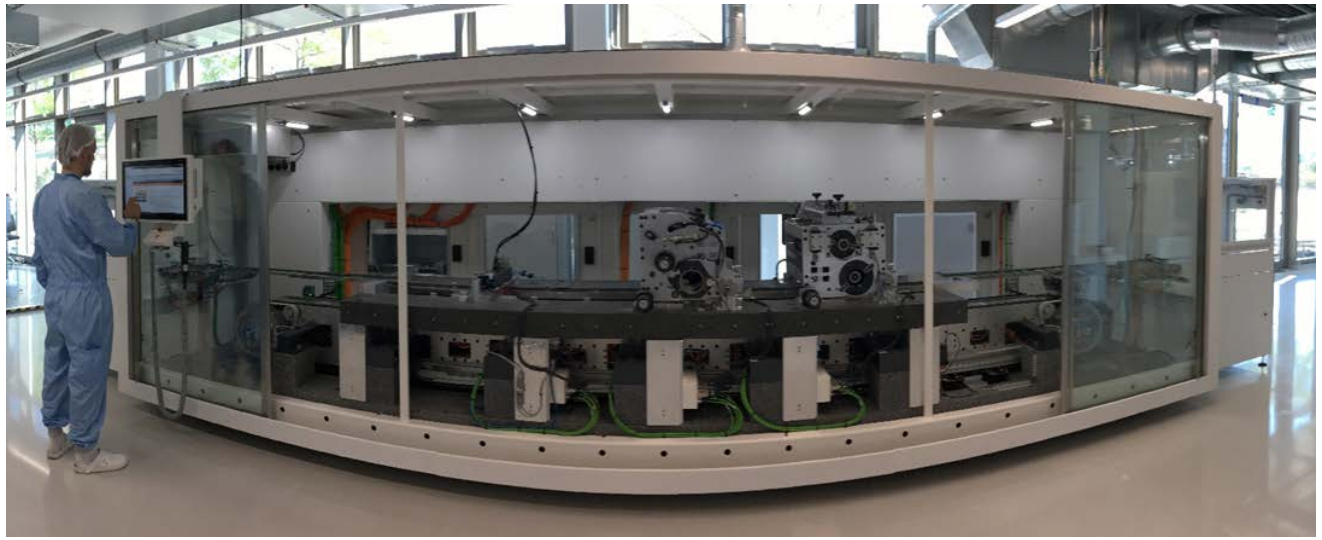
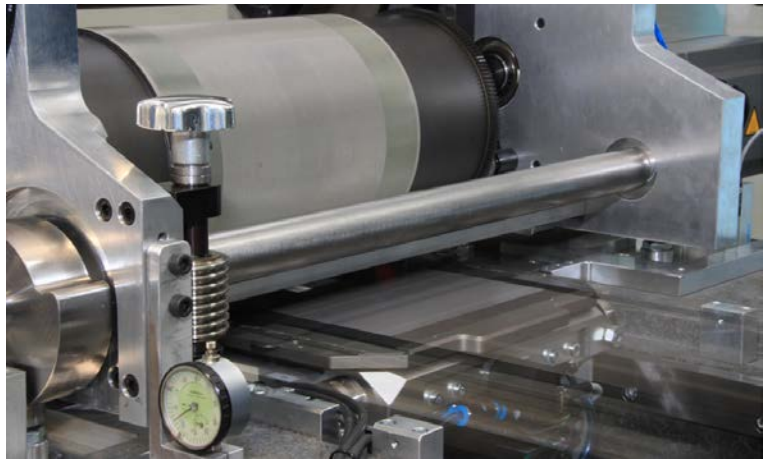
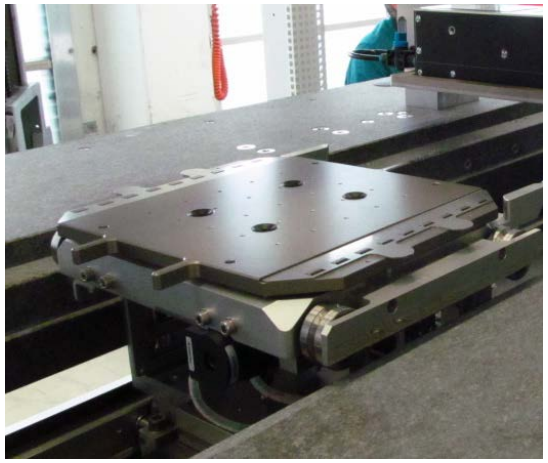
»Rock-Star« Demonstrator
Highlights and technical data

»Rock-Star« Demonstrator:

- Machine platform designed and realized by Asys
- Rotary Screen and Flexo printing unit (Gallus)
- Innovative high-speed shuttle transport
- Ultra-fast alignment by high-speed cam
- Cycle time per wafer: **< 0.5 s**
  → up to 8000 cells/h in inline production
- Batch production of 60 wafers/run







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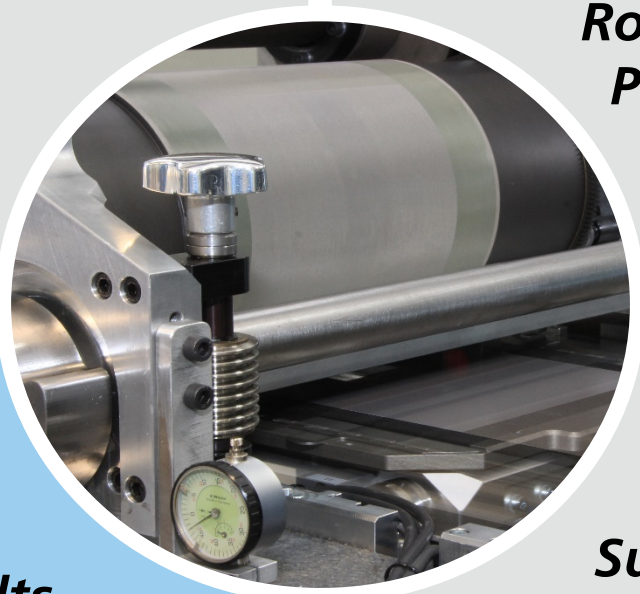

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Summary of Results and Outlook

Rotary screen printed metallization of SHJ solar cells

Aim of Experiment and Experimental Setup

Aim of Experiment

- Fabrication of **fully rotary screen printed** bifacial silicon heterojunction (SHJ) solar cells

Setup:

- Industrial bifacial SHJ precursors with TCO (156.75 mm x 156.75 mm)
- Gallus rotary screen with 325 mesh
- Namics low-temperature Ag paste, diluted with 3 wt% thinner
- Busbarless layout (RS: 150 F/ FS: 80 F)
  Nom. finger width w_n: 30 µm/40 µm
- Reference group with flatbed screen printed front & rear metallization

Group 1 (Rotary 40 µm)	Group 2 (Rotary 30 µm)	Group 3 (Reference)
Industrial SHJ precursor incl. TCO (Bifacial)		
Rear side grid Rotary SP, 150 finger w_n = 30 µm	Rear side grid Rotary SP, 150 finger w_n = 40 µm	Rear side grid Flatbed SP, 150 finger w_n = 40 µm
Drying & Curing, $T \approx 200°C$, t ≈ 10 min.		
Front Side Grid Rotary SP, 80 finger w_n = 30 µm	Front Side Grid Rotary SP, 80 finger w_n = 40 µm	Front Side Grid Flatbed SP, 80 finger w_n = 40 µm
Drying & Curing, $T \approx 200°C$, t ≈ 10 min.		
I-V-Characterization (GridTouch on industrial cell tester)		
3D confocal microscopy of contacts + image analysis (Dash)		
Scanning electron microscopy of contacts		

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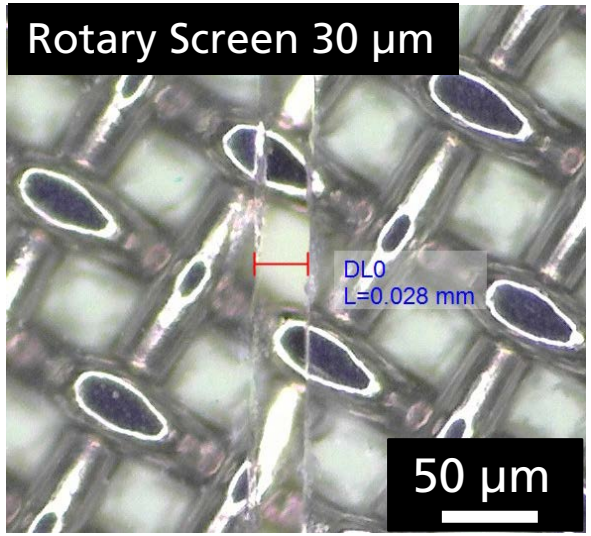
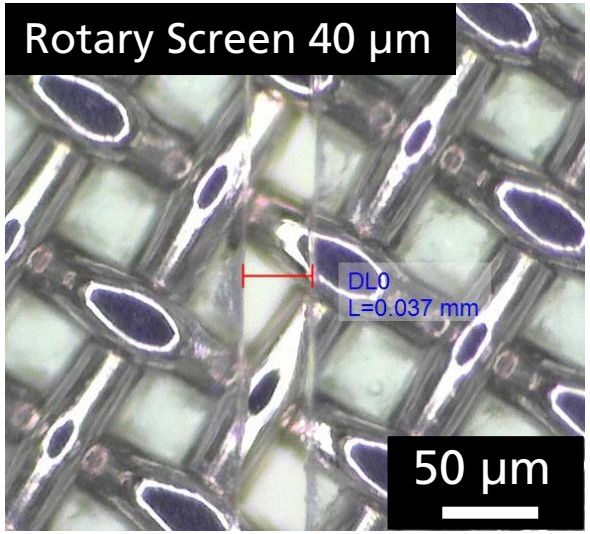
Rotary screen printed metallization of SHJ solar cells
Experimental Setup

Rotary Screens:

- Excellent quality of finger channels (finger width tolerance ~ 2-3 µm)
- Mounting of screens with gear rings at Fraunhofer ISE





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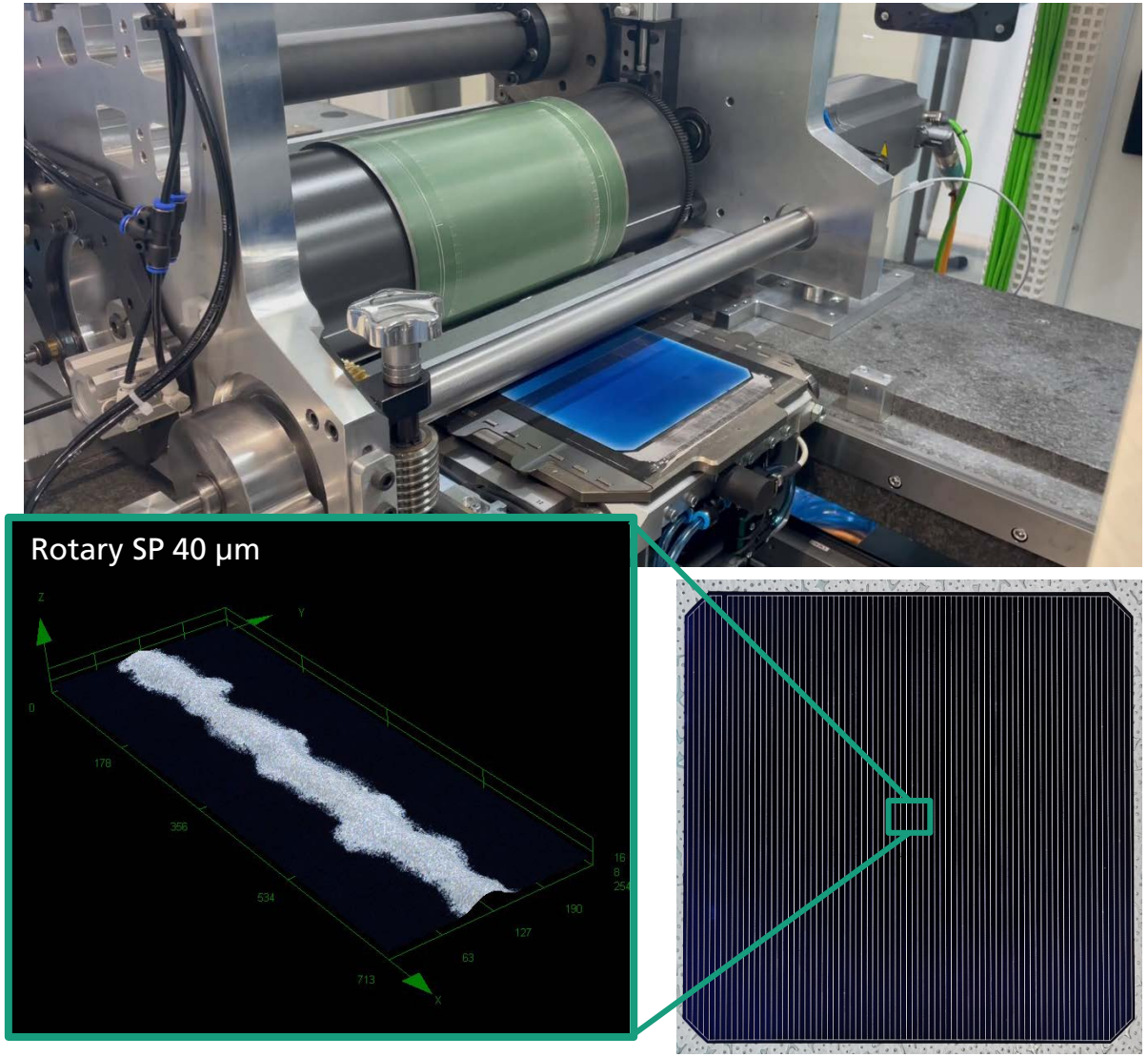
Rotary screen printed metallization of SHJ solar cells

Printing Test

Printing on »Rock-Star« Demonstrator:

- Successful printing of 30 µm and 40 µm rotary screens
  → Good printing quality on both sides
- Machine velocity 50/70% (0.65 – 0.86 sec/wafer)



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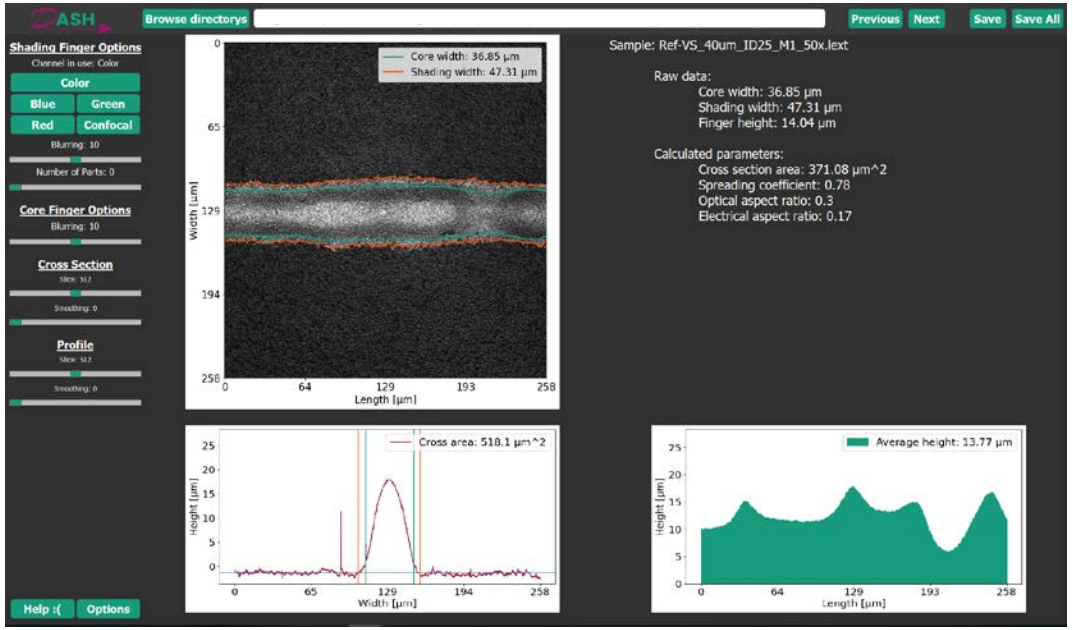
Rotary screen printed metallization of SHJ solar cells

Analysis of printing results

Analysis of finger geometry

- Olympus LEXT laser-scanning confocal microscope
- 10 Measurements per group on front side
- Image analysis of finger geometry using Fraunhofer ISE program *Dash*
- Average printed finger width w_f, finger height w_f, cross-section area A_f



Group	Method	Side	Nom. width w_n [µm]	∅ Width w_f [µm]	∅ Height h_f [µm]	∅ Cross section area A_f [µm²]
1	Rotary SP	FS	30	52 ± 3	5 ± 0.3	154 ± 12
2	Rotary SP	FS	40	53 ± 7	7 ± 0.4	201 ± 21
3	Flatbed SP	FS	40	47 ± 1	15 ± 0.6	386 ± 20

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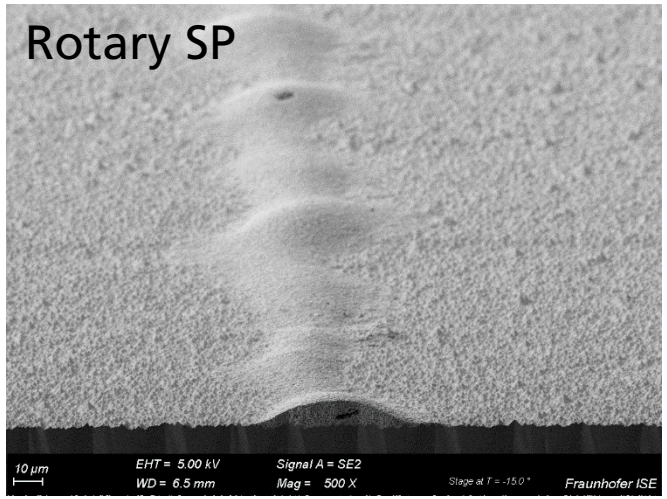
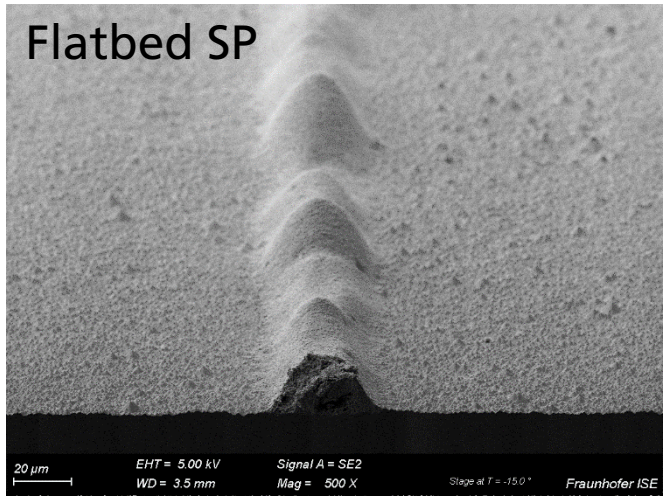
Rotary screen printed metallization of SHJ solar cells

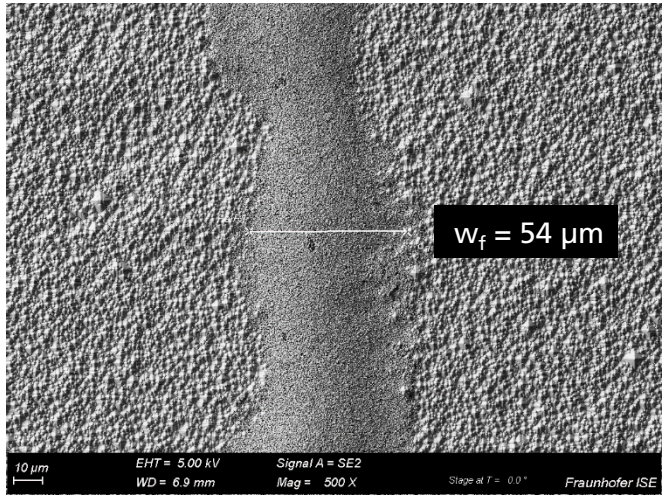
Analysis of printing results

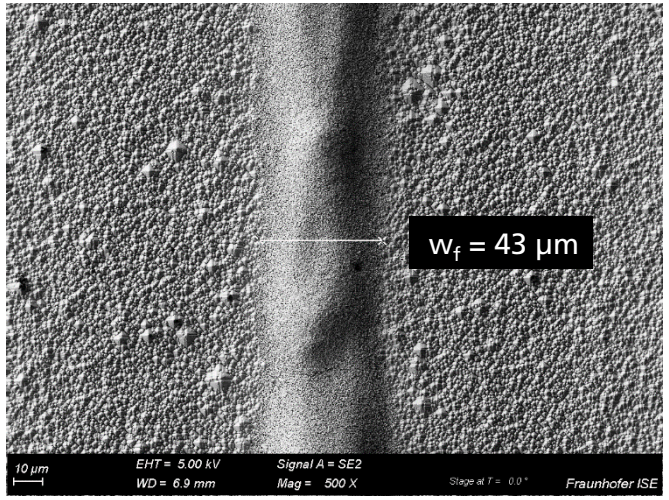
Results:

- Rotary screen printed fingers currently ~5-10 µm broader compared to FSP fingers
- Finger height and cross section area **reduced by ~50-75 %**
- Existing challenges:
  - Finger uniformity (mesh marks, spreading)
  - Reduction of finger width









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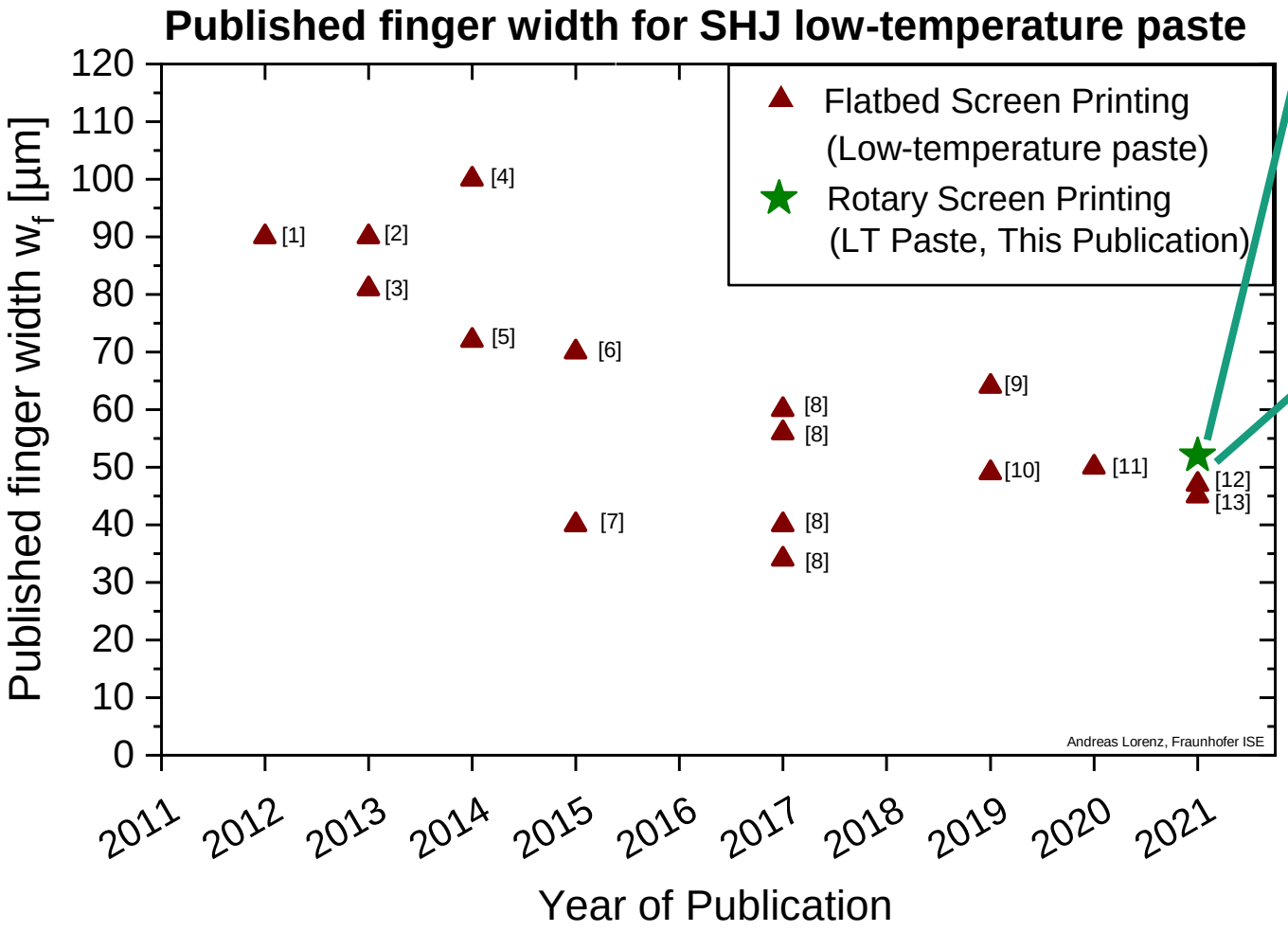
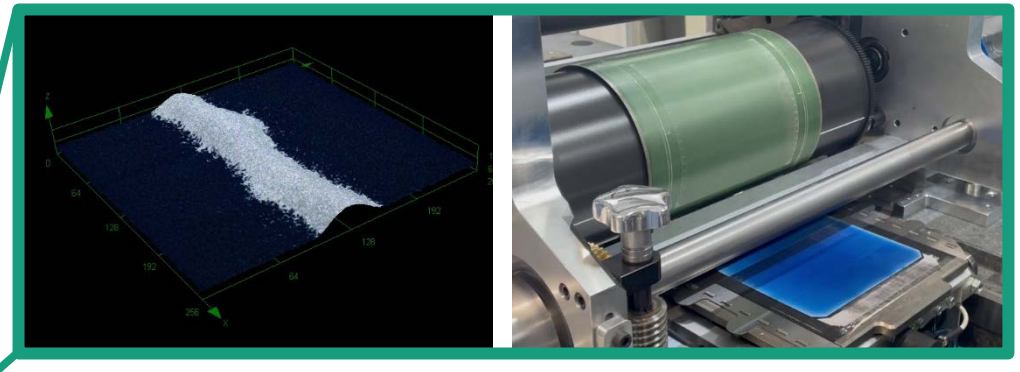
Rotary screen printed metallization of SHJ solar cells

Analysis of printing results





References:

[1] Hernández et al., Jpn. J. Appl. Phys. 51 (2012)
[2] Chien et al., Conf. Rec. 39th IEEE PVSC (2013)
[3] Khanna et al., Proc. 28th EUPVSEC (2013)
[4] Serenelli et al., Conf. Rec. 40th IEEE PVSC (2014)
[5] Geissbühler et al., IEEE J. Photovolt. 4 (2014)
[6] Geissbühler, PhD Thesis, EPFL Lausanne (2015)
[7] Descoeudres et al., Energy Proc. 77 (2015)
[8] Erath et al., Energy Proc. 124 (2017)
[9] Teo et al., Solar Energy 189 (2019)
[10] Schube et al., AIP Conf. Proc. 2156 (2019)
[11] Li et al., Solar Energy 196 (2020)
[12] Nam et al. Int. J. of Precis. Eng. and Manuf.-Green Tech. (2021)
[13] Donercark et al., Conf. Rec. 47th IEEE PVSC (2021)

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Rotary screen printed metallization of SHJ solar cells

Analysis of silver paste consumption

Analysis of silver paste consumption:

- Weighing of wafer before and after metallization (wet paste consumption)

Gr	Method	W_n [µm]	Side	Wet Ag paste consumption	
				Per Side [mg]	Total [mg]
1	Rotary SP	30	FS	11.3	37
1	Rotary SP	30	RS	26.1	
2	Rotary SP	40	FS	13.5	47
2	Rotary SP	40	RS	33.5	
3	Flatbed SP	40	FS	40.8	116
3	Flatbed SP	40	RS	74.8	

*wet paste (Printed pattern before drying/curing)

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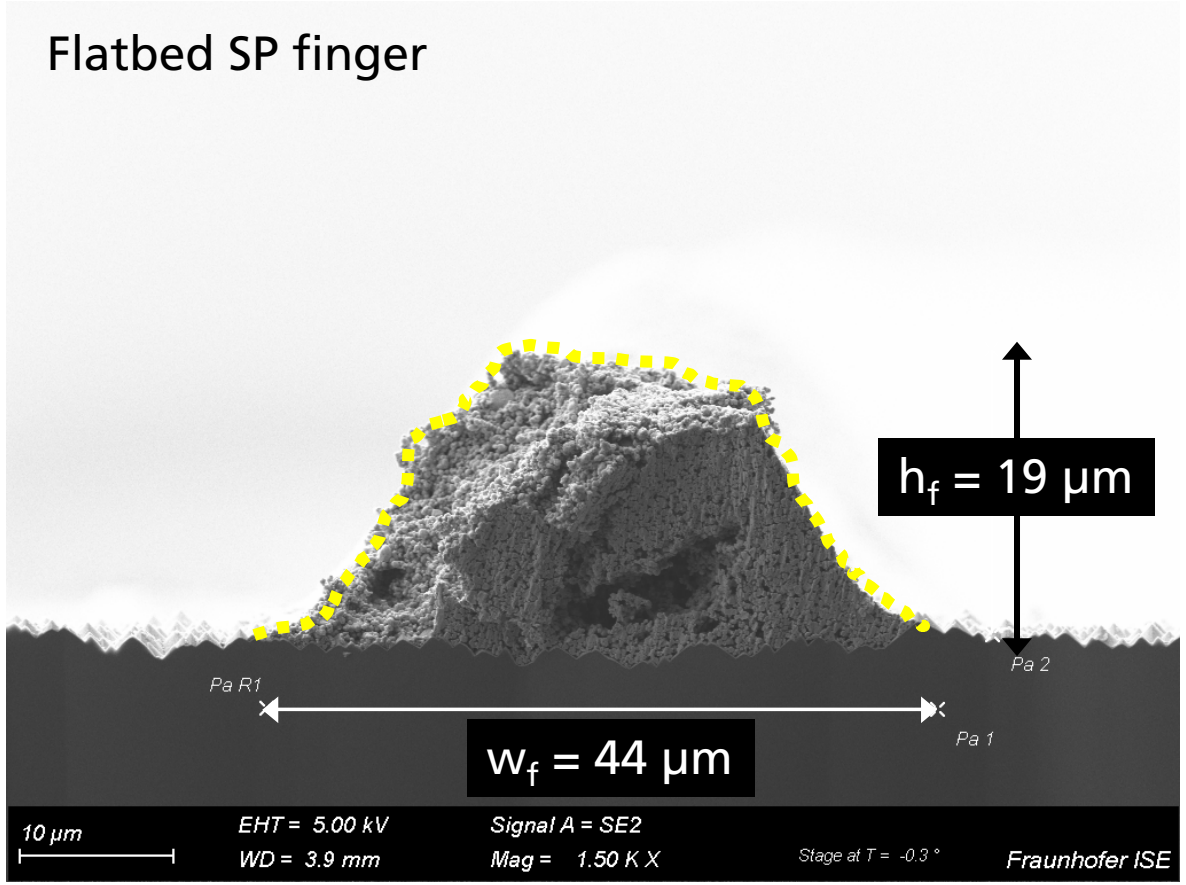
Rotary screen printed metallization of SHJ solar cells
Analysis of silver paste consumption

Analysis of silver paste consumption:

- Weighing of wafer before and after metallization (wet paste consumption)

Result:

- Rotary printed metallization: Substantial reduction of wet silver paste **~60%$_{abs}$** (40 µm grid) / **~70%$_{abs}$** (30 µm grid)
- Reduced finger height & cross section compared to flatbed screen printing



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Rotary screen printed metallization of SHJ solar cells

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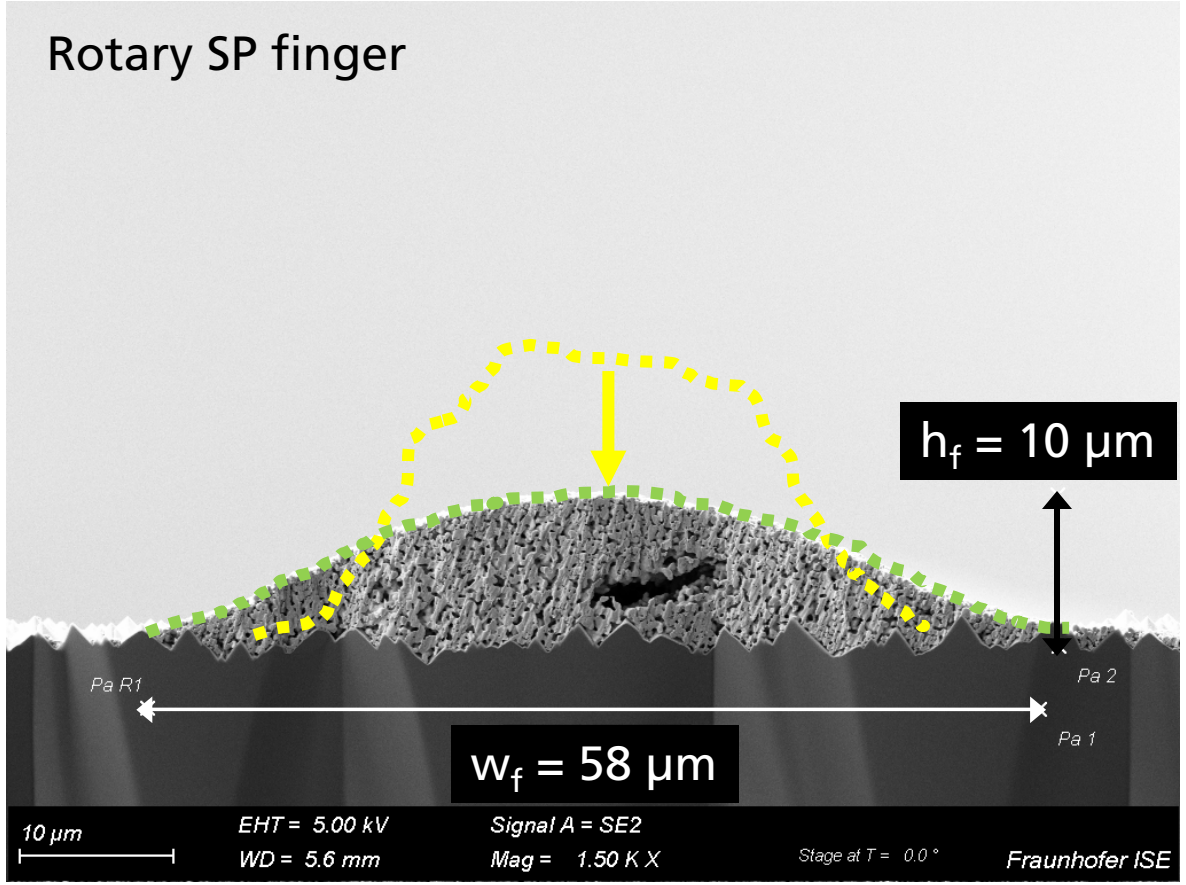

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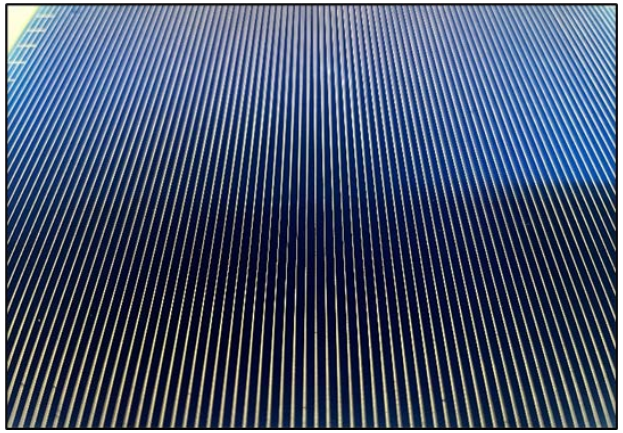
Rotary screen printed metallization of SHJ solar cells

I-V-Results of SHJ Solar Cells

I-V-Results:

- Solar cells measured after Light-Soaking step
- GridTouch unit in industrial cell tester
- Performance of material (SJH precursors) generally limited



Gr.	Method	Grid w_n [µm]	Avg/Best	Jsc [mA/cm²]	Voc [mV]	FF [%]	η [%]
1	Rotary SP	30	Avg	38.1	728	78.1	21.6
			Best Cell	38.0	730	78.6	21.8
2	Rotary SP	40	Avg	38.1	278	78.2	21.7
			Best Cell	38.3	730	79.1	21.8
3	Flatbed SP	40	Avg	38.2	729	78.8	22.0
			Best Cell	38.3	730	79.7	22.2

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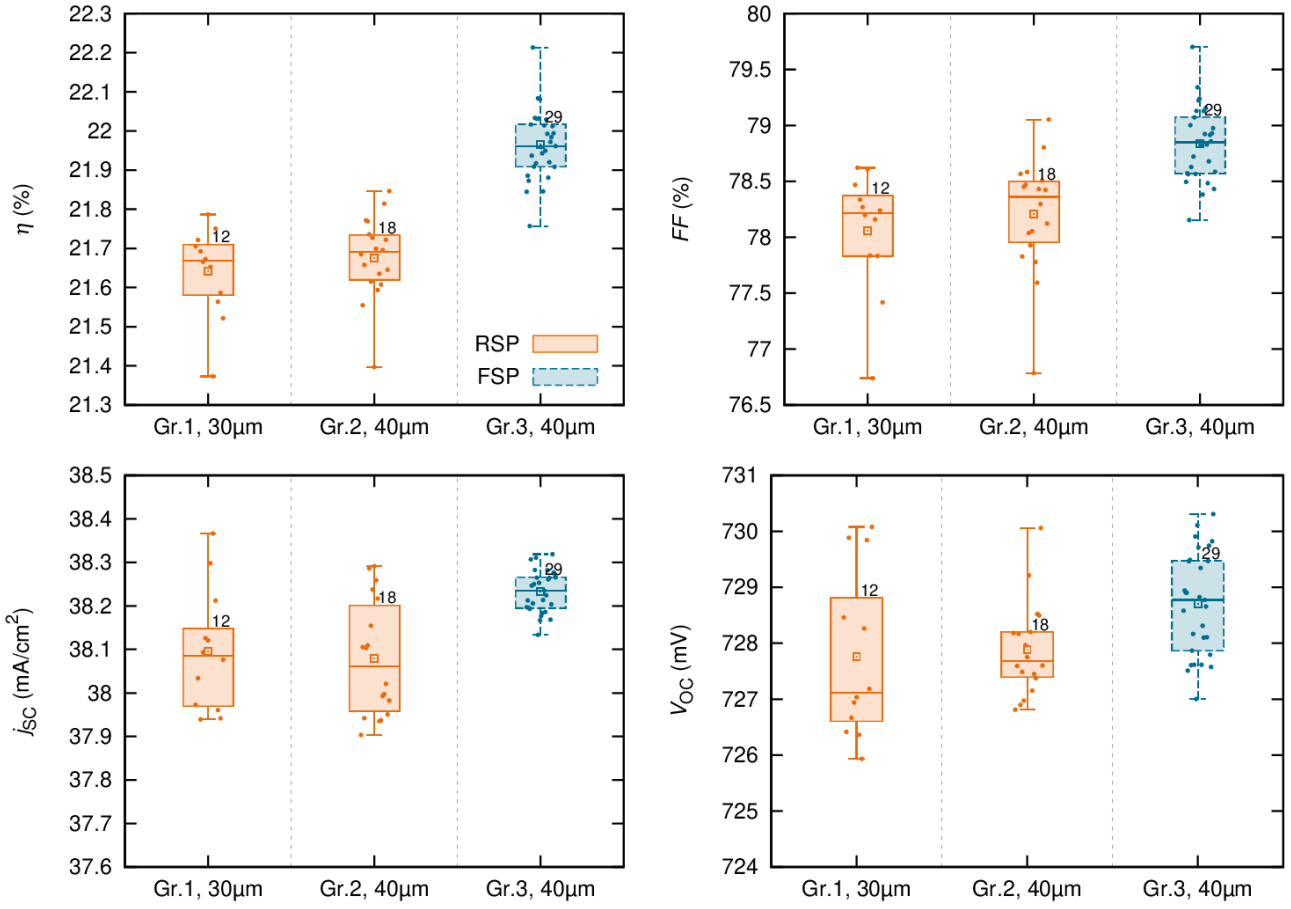
Rotary screen printed metallization of SHJ solar cells

Analysis of I-V-Results

I-V-Results:

- Conversion efficiency η of RSP metallized cells around $\Delta\eta$ ~ 0.3-0.4 $\%_{abs}$ lower than FSP reference
- Primarily FF-losses:
  - Optimize finger uniformity on the front side (screen, paste)
  - Contacting of rotary printed grid in GridTouch unit
  - Alignment of rotary print on wafers (edge effects, shunting)



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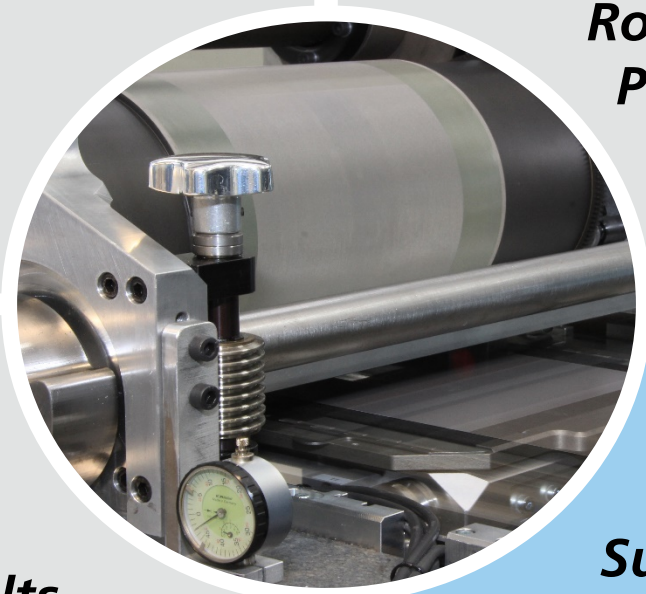

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Summary of Results and Outlook

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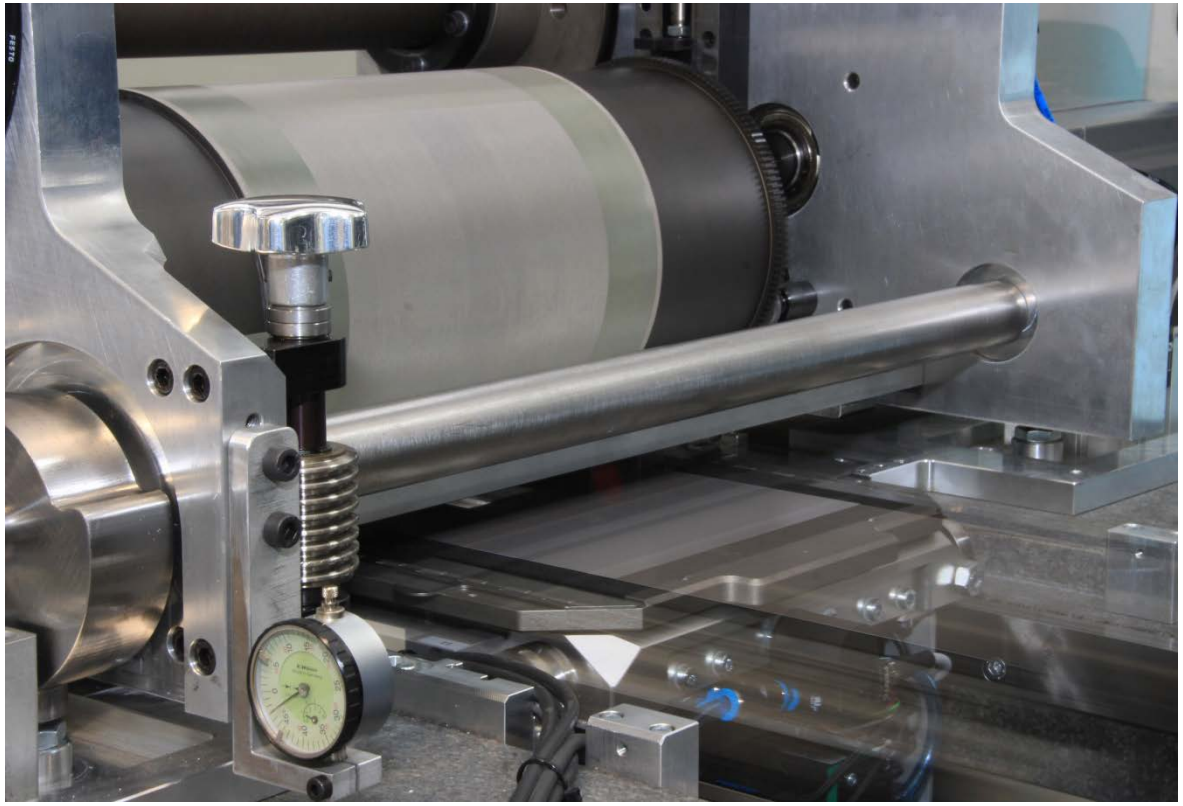
Summary and Outlook
Summary of Results

Summary:

- First fully rotary screen printed bifacial SHJ solar cells
- Cycle time down to 0.65 sec/cell
- Wet silver paste reduction by ~60-70 %
- Existing challenges:
  - Reduce FF losses
  - Optimize finger geometry and uniformity (paste, screens)
  - Optimize positioning accuracy of machine

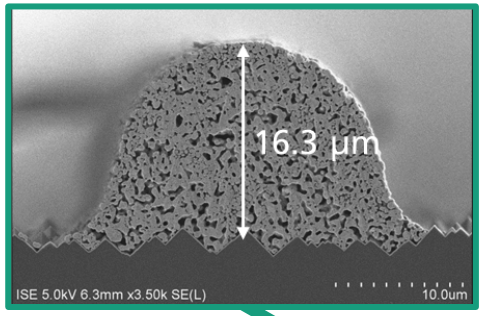


Summary and Outlook

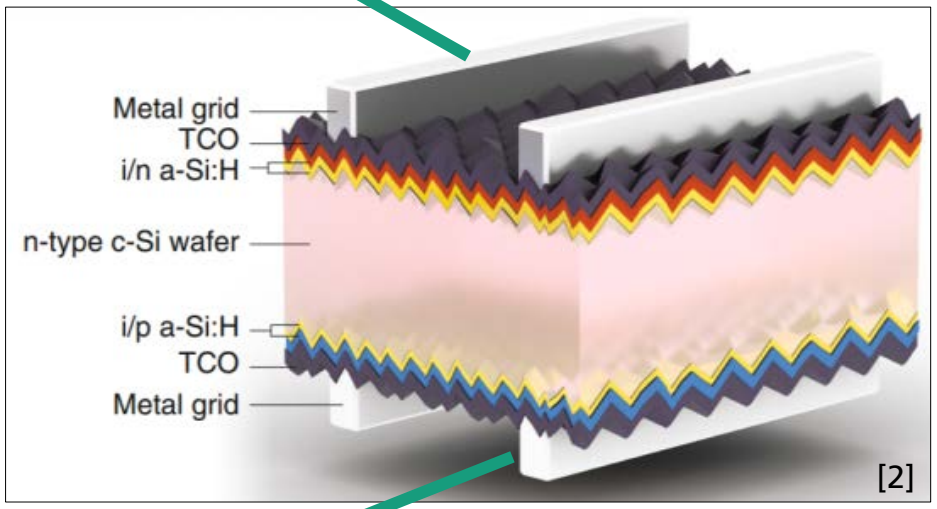
Outlook – Next Steps

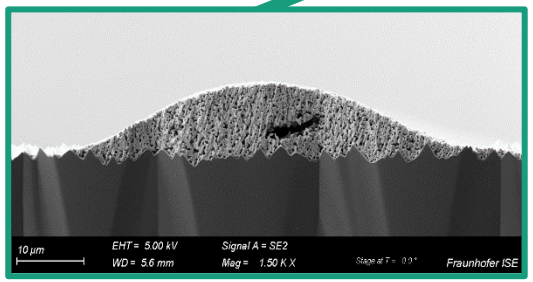
Outlook:

- Further optimization of materials (paste, screen) and rotary screen printing process
- Test of hybrid approach:
  - Parallel dispensing on front side
    → Perfect geometry
    → Fast process
  - Rotary screen printing on rear side
    → Substantial silver reduction
    → Fast process



Dispensed LTP contact on SHJ solar cell [1]





Rotary printed LTP contact on SHJ solar cell

[1] Gensowski et al., 9th Metallization Workshop / AIP Conf. Proc. 2367 (2021)
[2] Allen at al., Nature Energy (2019)

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Thank You!
Rotary Printing Project Team

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Thank You for Your Attention!

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