Towards a High-Throughput Metallization of Silicon Solar Cells using Rotary Screen Printing

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[d]IMTEK, Albert-Ludwigs-Universität, Freiburg

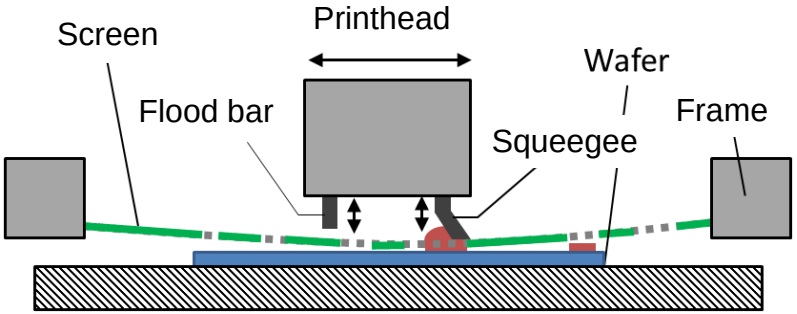
7th Metallization Workshop
Constance, Oct 23th -24th 2017

www.ise.fraunhofer.de

Motivation

Alternative Technologies for Solar Cell Metallization

- Today: Over 95% of industrial Si solar cells are metallized with flatbed screen printing (FSP)
- Double printing sequence (flooding – printing) limits throughput
- Actual throughput FSP: ~ 2400 W/h[2]



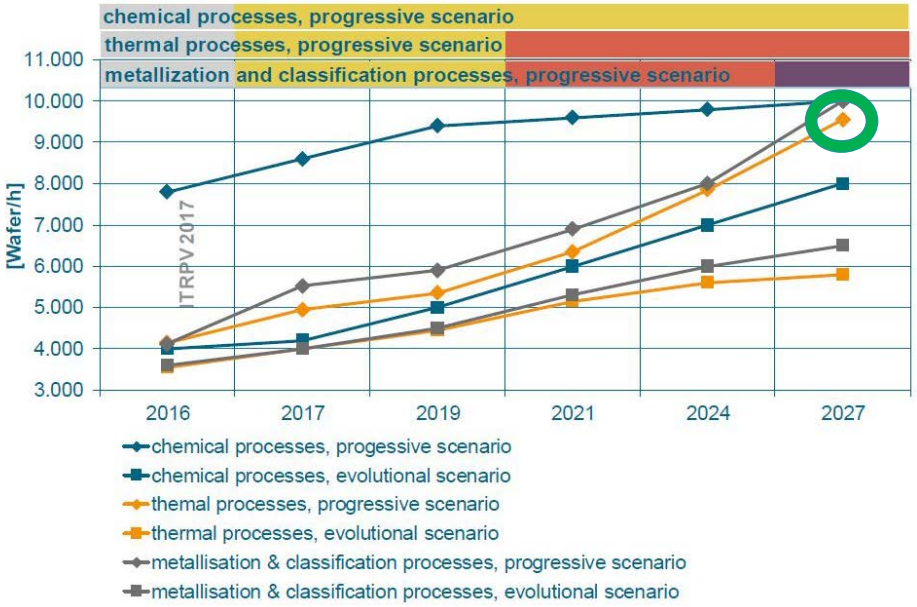
Schematic drawing of a flatbed screen printing unit for the metallization of Si solar cells

[1] Asys Solar Solutions, Metallization Lines (2016)

Motivation

Alternative Technologies for Solar Cell Metallization

- Strong need for higher throughputs
- ITRPV: Expected throughput for metallization processes in 2027: **up to 10000 Wafers/h**[2]



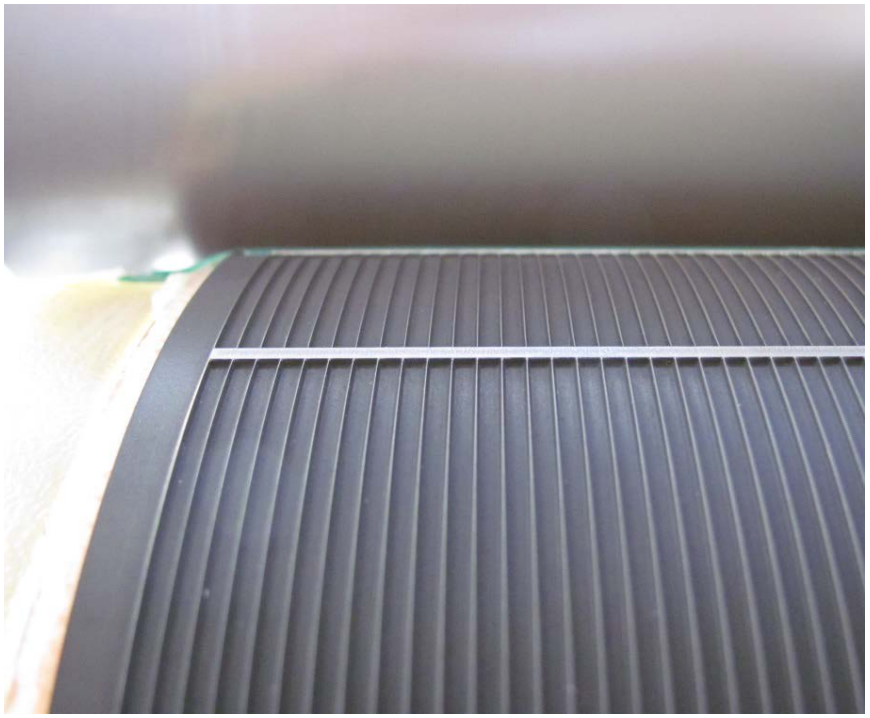
Forecast of the International Technology Roadmap for Photovoltaics (ITRPV) regarding the expected throughput of PV production lines[2]

[2] ITRPV Roadmap, 2017

Motivation

Alternative Technologies for Solar Cell Metallization

- Strong need for higher throughputs
- ITRPV: Expected throughput for metallization processes in 2027: **up to 10000 Wafers/h**[2]
- Approach: **High-speed rotary printing processes**
- Target throughput: Up to **8000 Wafers/h** on a single line



Flexographic printing plate with fine line front side grid layout

[2] ITRPV Roadmap, 2017

Joint Project
„Rock-Star“

- Joint project „Rock-Star“
- 7 project partners
- Time scale: 01.09.2015 – 31.08.2018
- Supported by the German Federal Ministry of Education and Research (BMBF) (Photonics Research Germany)
- Aim of project:
  - Evaluation of rotary printing methods
  - Development of a platform with rotational printing units

Project Consortium:

ASYS SOLAR, gallus, Continental CONTITECH, Fraunhofer ISE, idd printing science technology

Associated partners:

Q CELLS a Hanwha company, ZECHER

Gefördert von

Bundesministerium für Bildung und Forschung

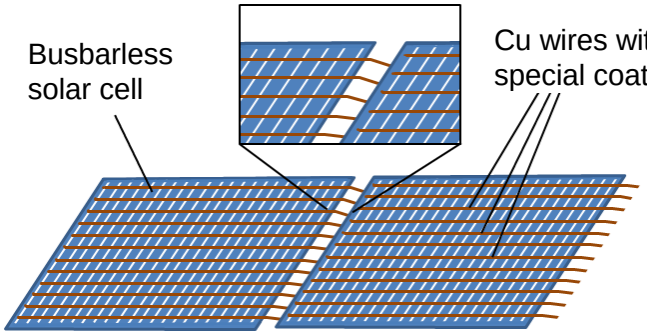
Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

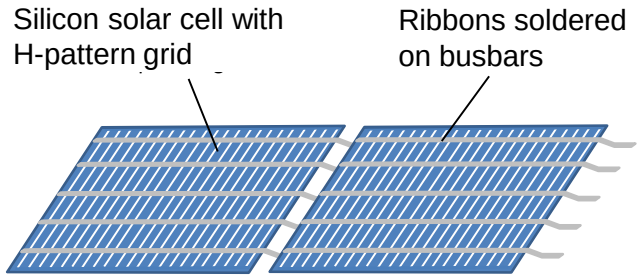
ASYS SOLAR, gallus, Continental CONTITECH, idd printing science technology, Fraunhofer ISE

Motivation
Roadmap

Busbarless solar cells with multi-wire interconnection

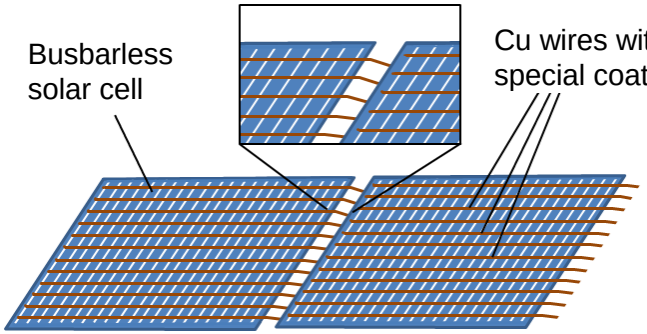


H-pattern solar cells with soldered ribbons



Motivation
Roadmap

Busbarless solar cells with multi-wire interconnection



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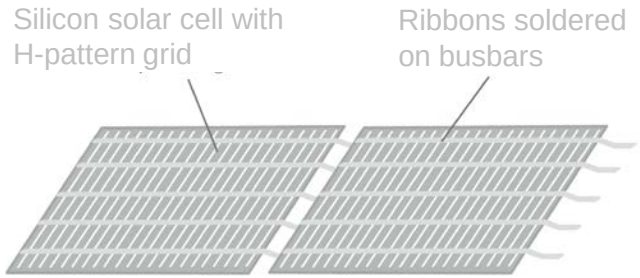
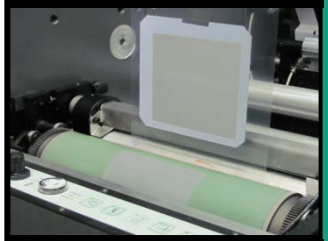


Rear Side Al



Rot. Screen Printing

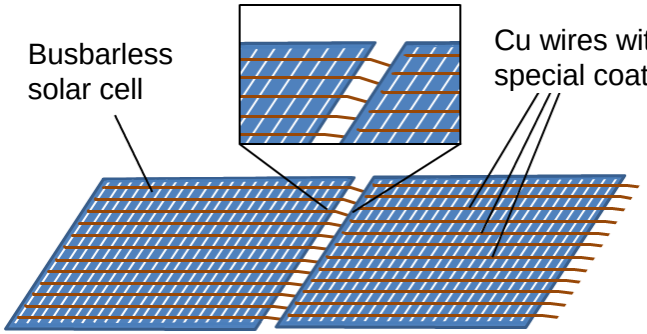
Front Fingers

Flexo Printing

Busbarless Cell

Motivation
Roadmap

Busbarless solar cells with multi-wire interconnection



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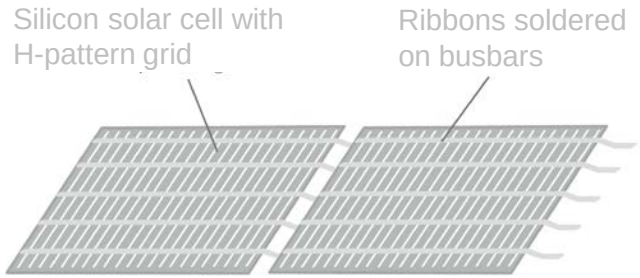
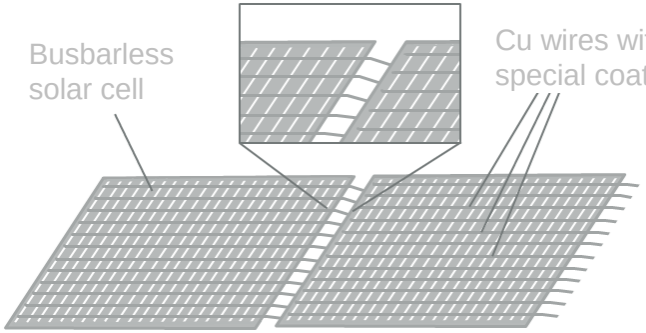


[3] Lorenz et al., 6th Metallization Workshop (2016)

Motivation
Roadmap

Busbarless solar cells with multi-wire interconnection



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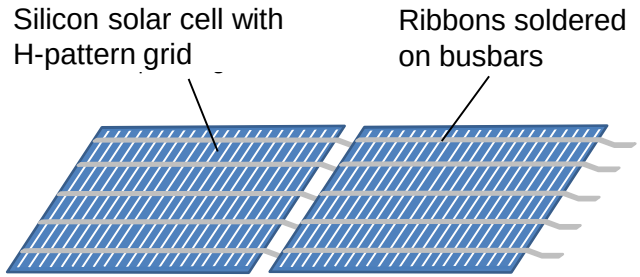

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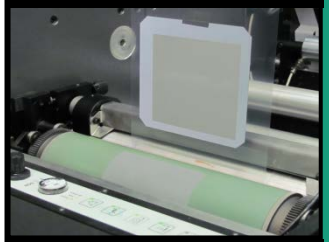
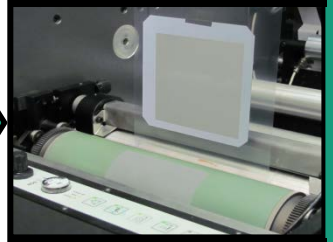


Rot. Screen Printing

Front Busbars



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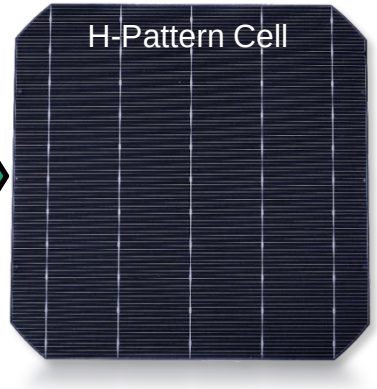
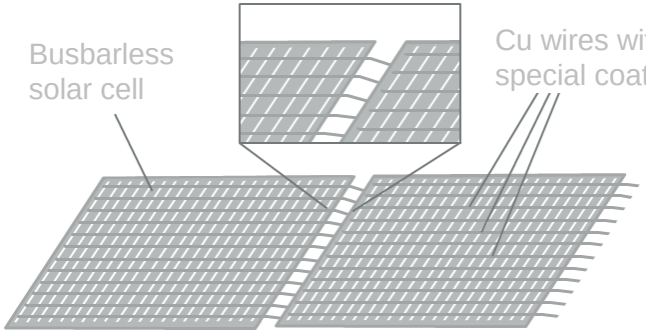
Flexo Printing

H-Pattern Cell

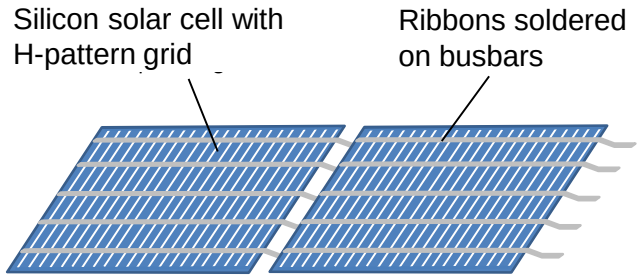


Motivation
Roadmap

Busbarless solar cells with multi-wire interconnection



H-pattern solar cells with soldered ribbons



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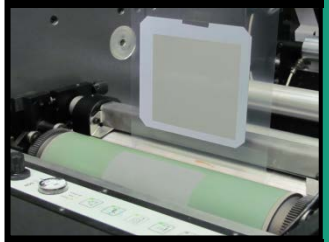

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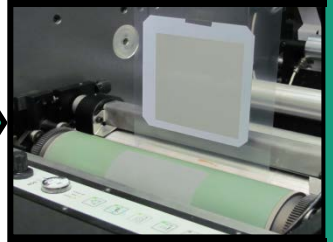

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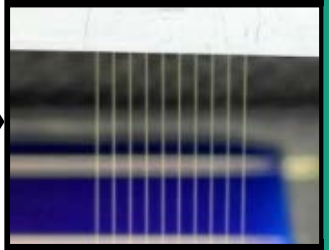

Dispensing

H-Pattern Cell

Motivation
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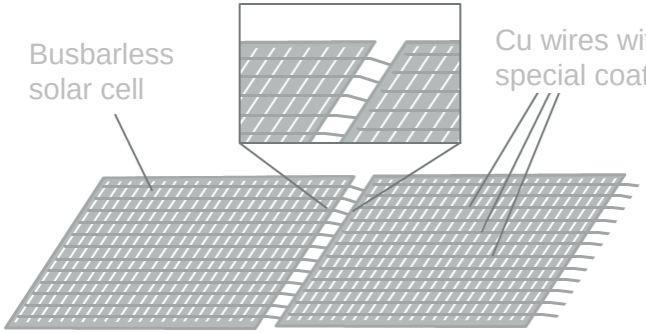
Busbarless solar cells with multi-wire interconnection



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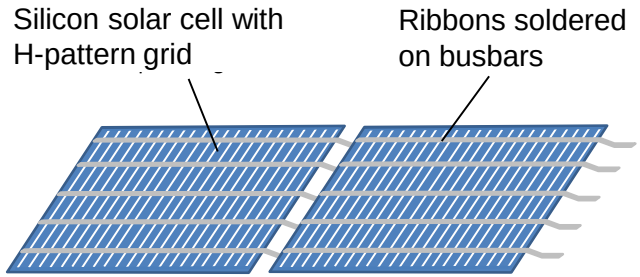

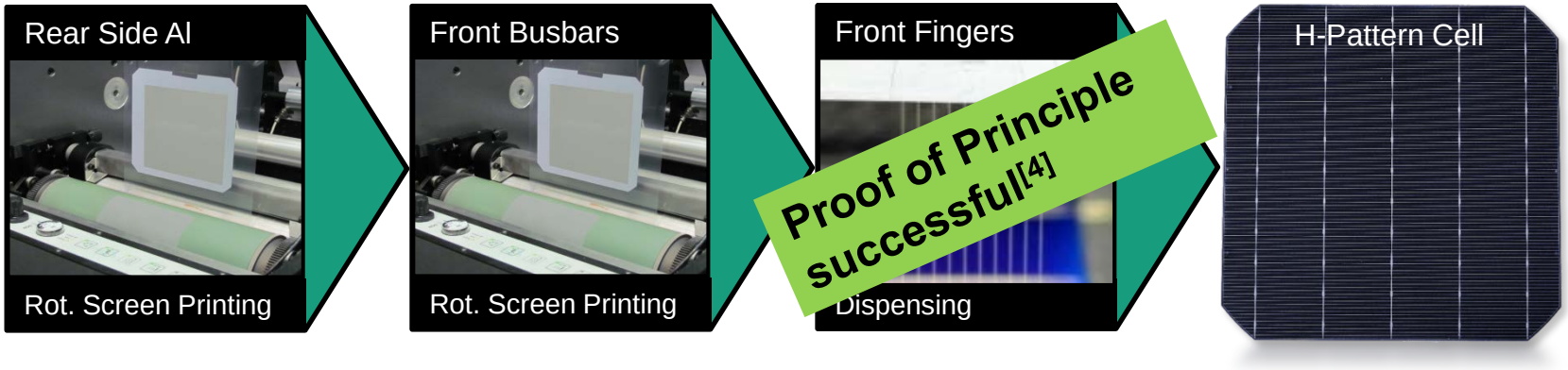

[4] Pospischil et al., 6th Metallization Workshop (2016)

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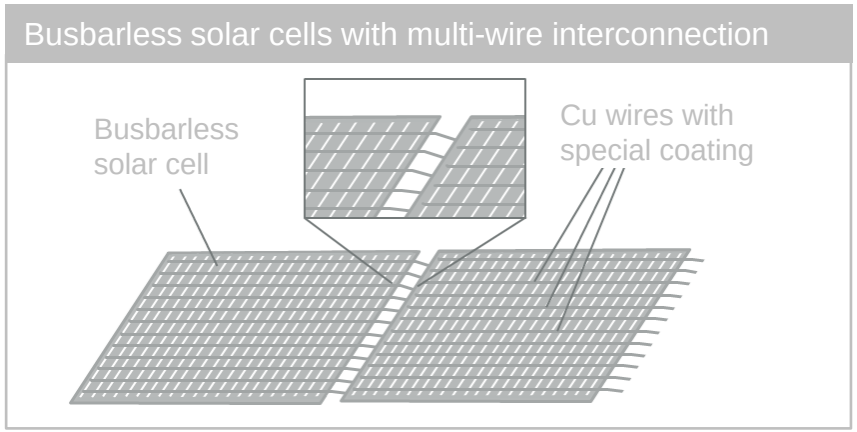

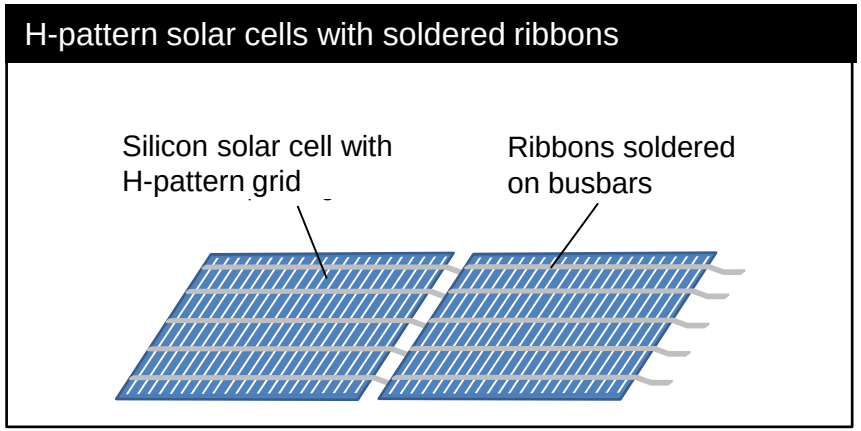

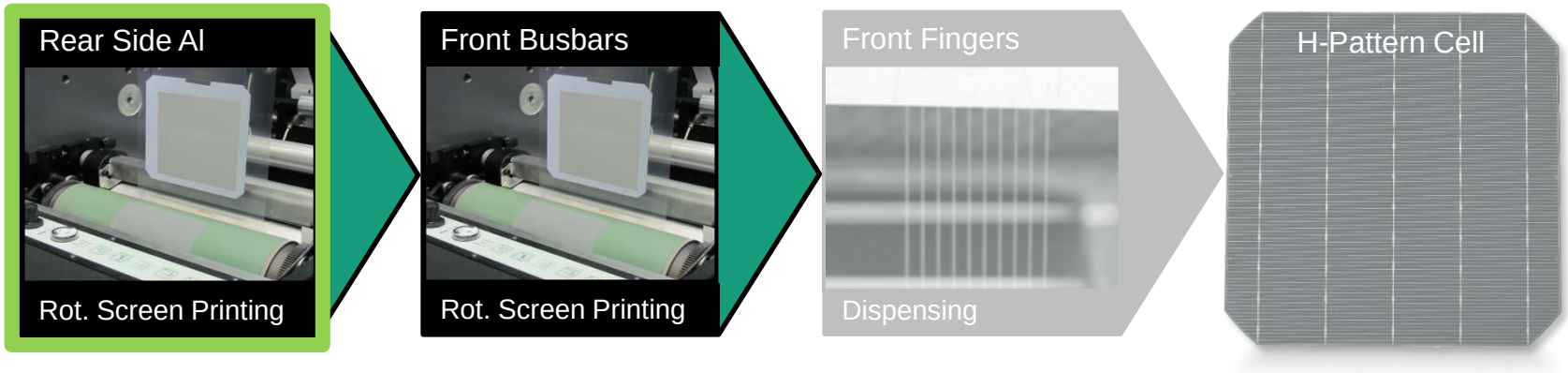

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Approach
Rotary Screen Printing Technology (RSP)

- Widely used in textile and label printing on roll-to-roll machines
- Printing speed up to 165 m/min.[5]
- Potential application for Solar Cells evisioned in 2000[6]

Source: Gallus Ferd. Rüesch AG

Label printing machine Gallus EM280

Source: Indian Textile Magazine

Rotary screen printing machine for textile printing

[5] Datasheet Gallus ECS 340 (260)
[6] Hahne, PhD Thesis (2000)

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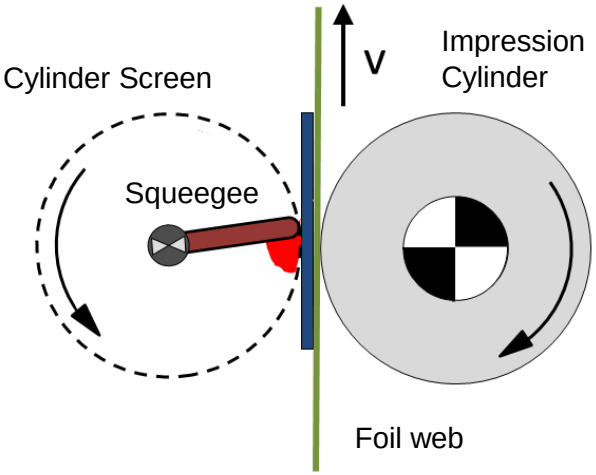

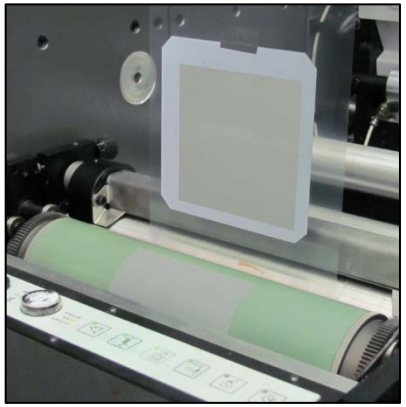

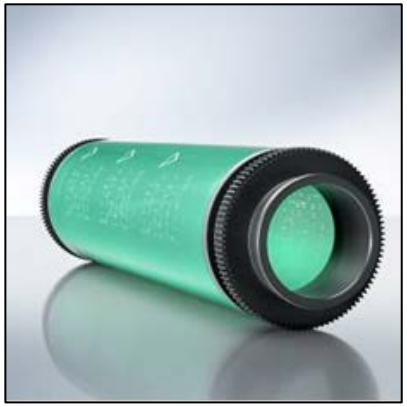

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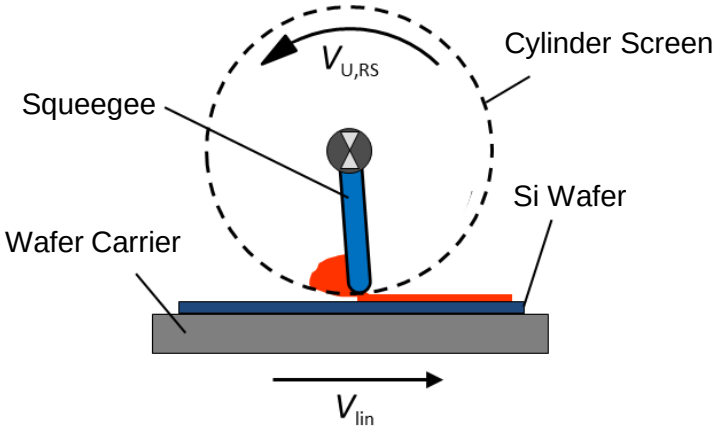

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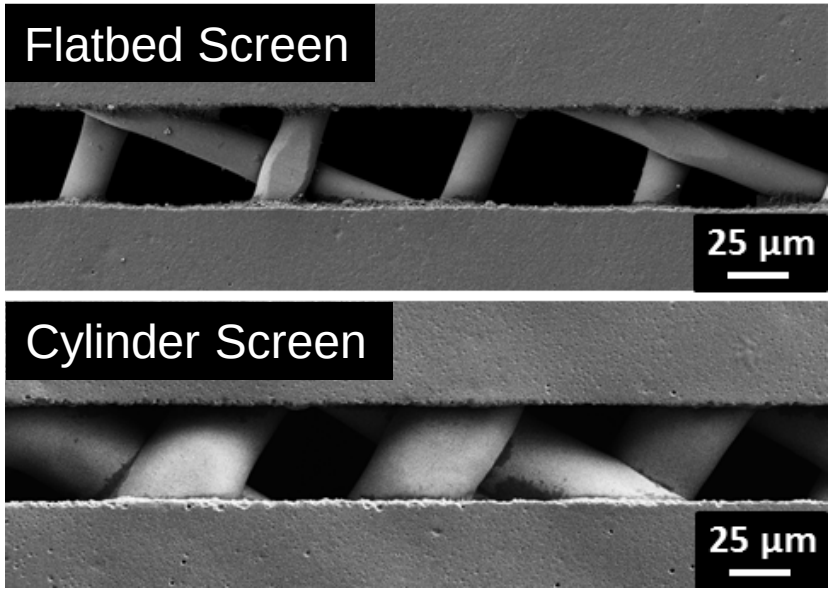
Approach
Rotary Screen Printing Technology (RSP)

- Difference to flatbed screen printing:
  - Continous printing process
  - Much faster printing sequence
  - Thicker wires of screen mesh
  - Slightly lower viscosity of paste

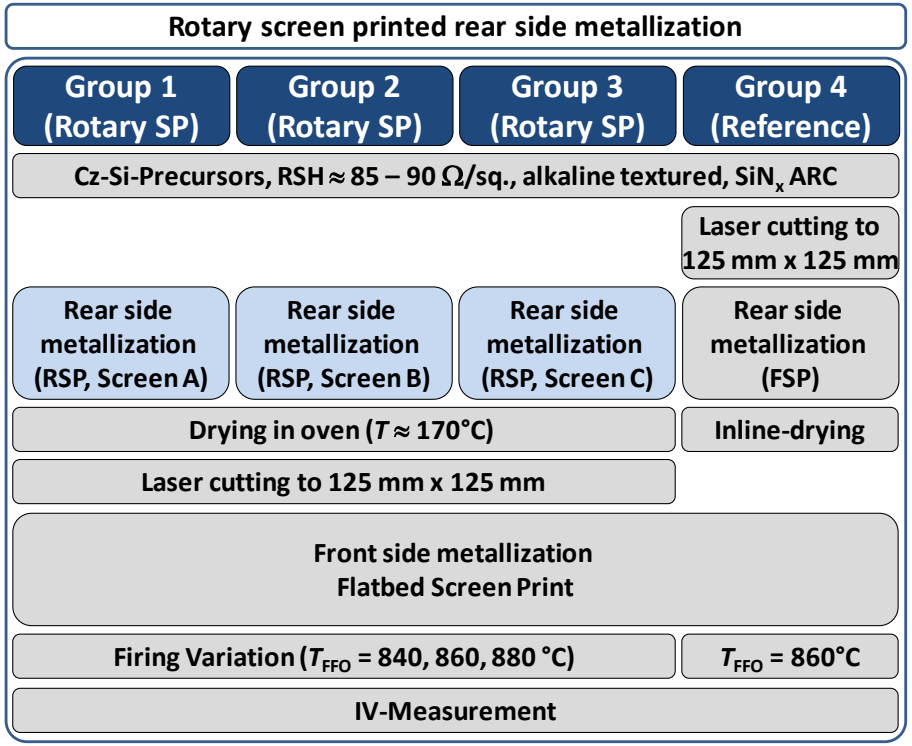


SEM-Image of a fine line opening within a flatbed screen and a cylinder screen

Rear side metallization of Al BSF solar cells

Experimental Setup

- Feasibility study on Al BSF[a] solar cells
- p-type Cz-Si Wafers (156 mm x 156 mm²)
- Laser cutting to size 125 mm x 125 mm
- RSP: 3 Rotary screens (different meshes), slightly diluted Al paste
- FSP reference group with standard screen
- Front side: Flatbed screen printing (85 fingers, nom. Finger width w_n = 50 µm)

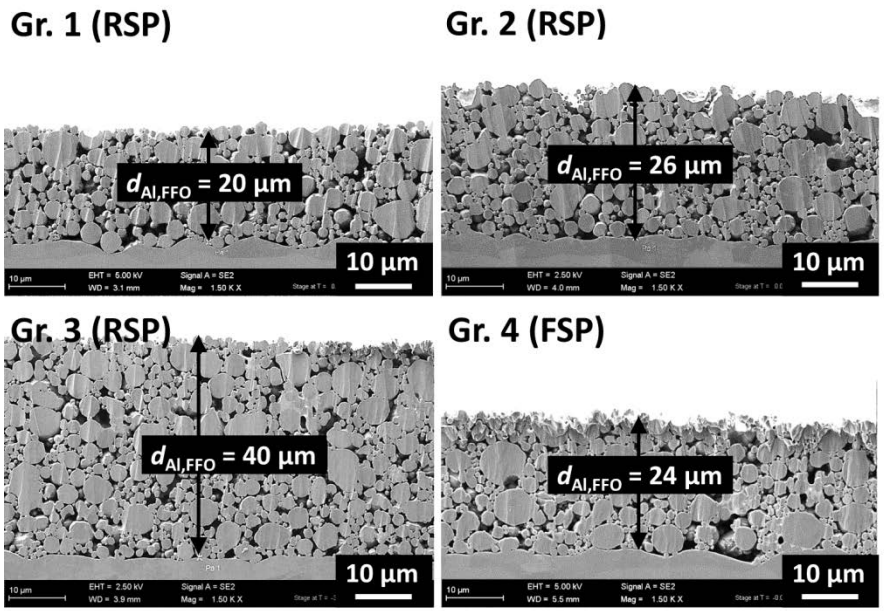


Experimental setup

[a]Aluminium Back Surface Field

Experimental Results
Comparison of rear side metallization

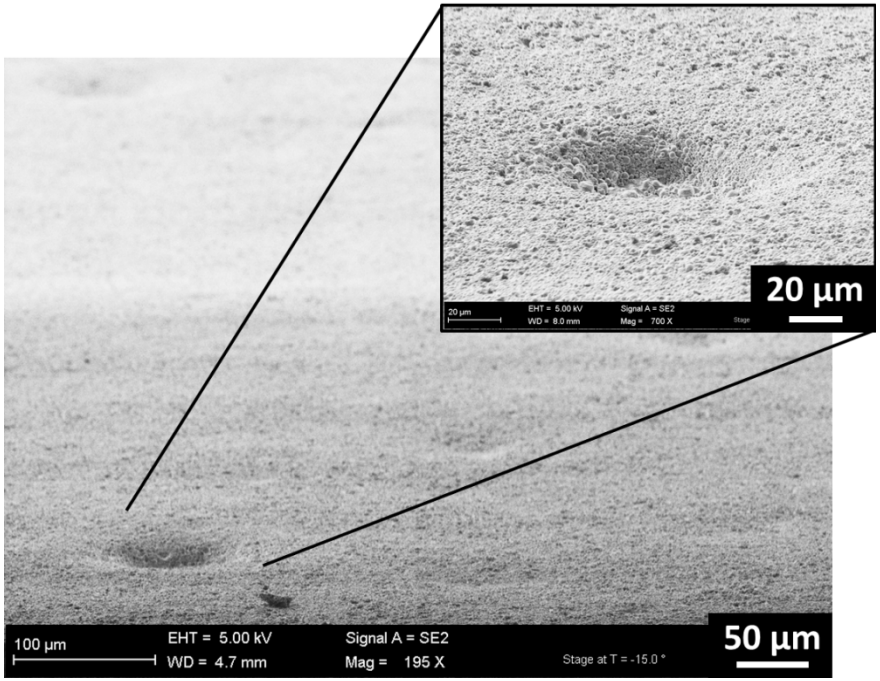
- Rotary screen printing (Gr. 1 – 3):
  - $d_{Al,FFO}$ = 20 – 40 µm (depending on screen mesh)
- Flatbed screen printing (Gr. 4):
  - $d_{Al,FFO}$ = 24 µm



SEM cross-section images of the rear side metallization

Experimental Results
Comparison of rear side metallization

- Typical pinholes in rear side Al visible on all cells
- No quality differences between RSP and FSP rear side Al layers



SEM image of FSP rear side metallization with pinholes

Experimental Results

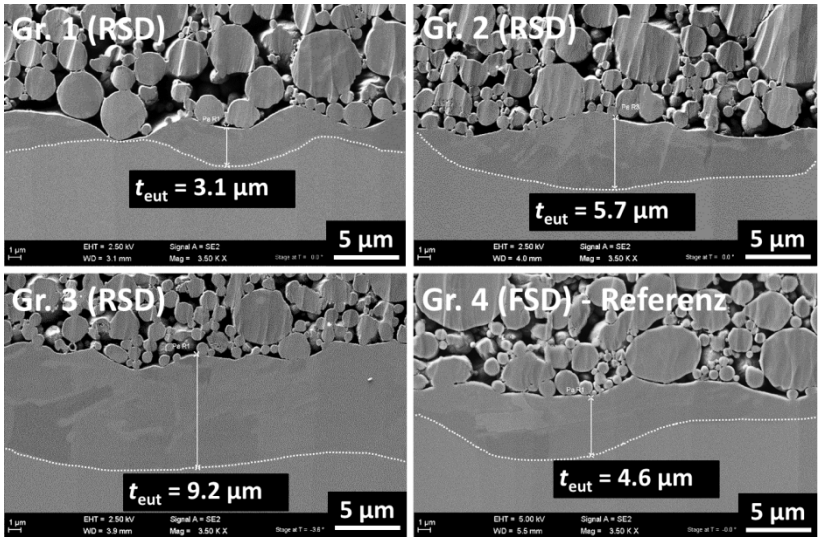
Impact of initial Al thickness on the Al-Si-eutectic

- Depth of eutectic layer depends on the mass/initial thickness of the rear side Al layer[7]

$$t_{eut} = \frac{m_{Al}}{A \cdot \rho_{Si}} \cdot \frac{S_{Si,melt}(T_{eut})}{1 - S_{Si,melt}(T_{eut})}$$

- Depth of the Al-doped p+ Si region depends on initial mass of Al and effective peak set temperature[7]

$$t_{Al-p^+} = \frac{m_{Al}}{A \cdot \rho_{Si}} \cdot \left[\frac{S_{Si,melt}(T_{peak})}{1 - S_{Si,melt}(T_{peak})} - \frac{S_{Si,melt}(T_{eut})}{1 - S_{Si,melt}(T_{eut})}\right]$$



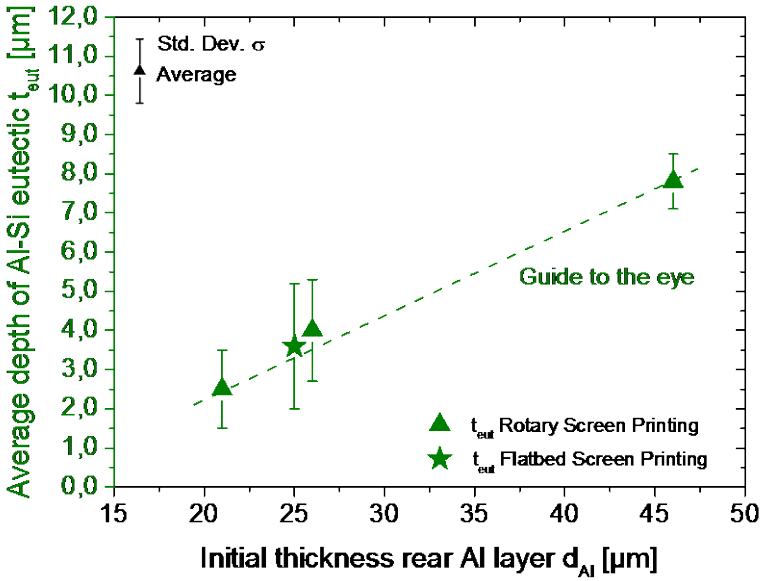
SEM cross-section images of the Al BSF. A considerable impact of the initial Al thickness d_{Al} on the depth of the Al BSF is visible

[7] Rauer, PhD Thesis (2015)

Experimental Results

Impact of initial Al thickness on the Al-Si-eutectic

- Results confirm a linear dependency between d_{Al} and t_{eut} which is consistent with the model of Rauer[7]
- Depth of eutectic layer t_{eut} on the same level for group 2 (RSP) and group 4 (FSP)



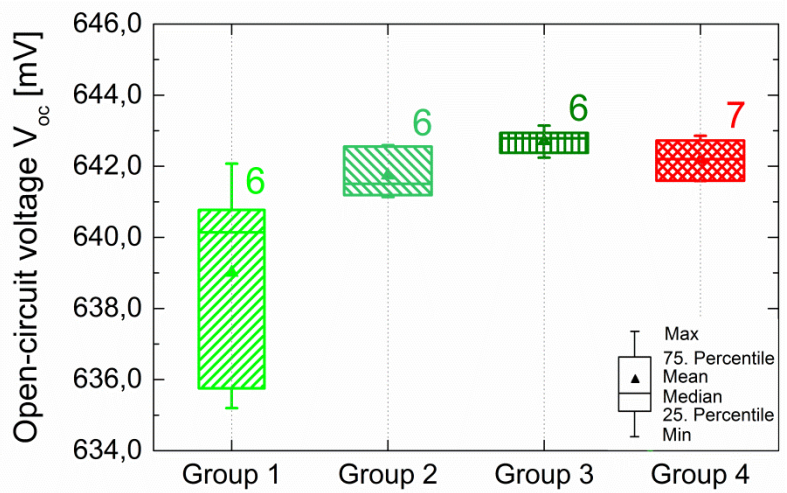
Relation between the initial thickness of the rear Al layer d_{Al} and the resulting depth of the Al-Si eutectic t_{eut}

[7] Rauer, PhD Thesis (2015)

Experimental Results

Impact on V_{oc} and $R_{SH,rear}$

- Differences in V_{oc} caused by different effectivity of the rear side Al BSF
- Thickness d_{Al} of groups 2 and 3 sufficient
- Strong bowing phenomena for cells of group 3
- *FF* loss due to the rear side sheet resistance $R_{SH,rear}$ acceptable for all groups

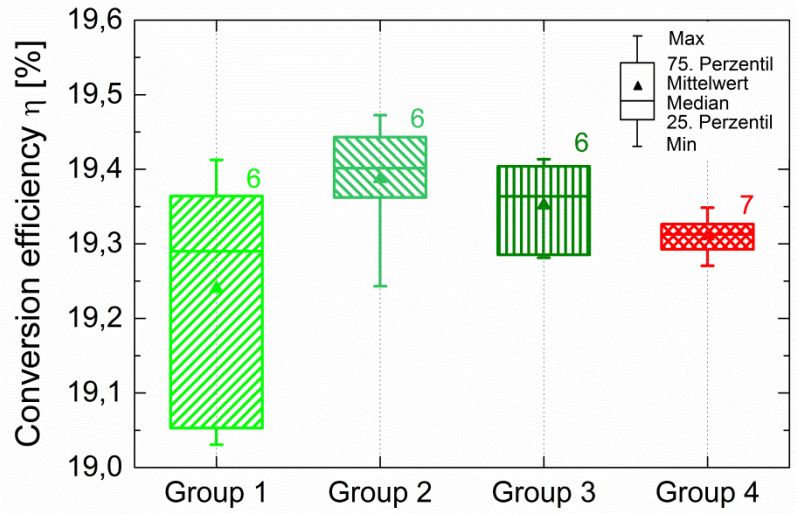


Exp. Group	$R_{SH,rear}$ [mΩ/sq.]*	ΔFF_{rear} [%]
Group 1 (RSP)	19.7 ± 0.5	0.016
Group 2 (RSP)	12.4 ± 0.2	0.010
Group 3 (RSP)	4.3 ± 0.1	0.004
Group 4 (FSP)	14.0 ± 0.3	0.011

*Normalized to a layer thickness of 25 µm

Experimental Results
I-V-Results of solar cells

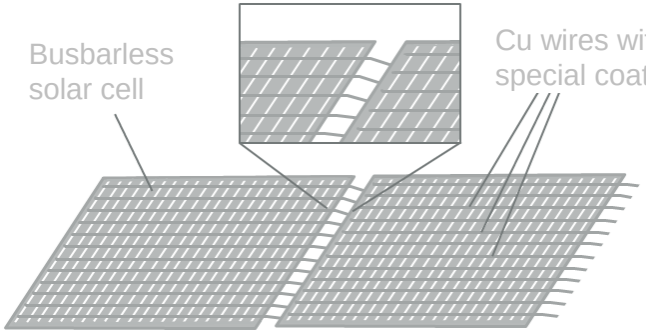
- Groups 2 and 3 achieved comparable conversion effiency to reference FSP group 4:
  - Group 2 (RSP): $\eta_{\varnothing}$ = 19,4 %
  - Group 3 (RSP): $\eta_{\varnothing}$ = 19,3 %
  - Group 4 (FSP): $\eta_{\varnothing}$ = 19,3 %



Conversion efficiency η of the four experimental groups

Motivation
Roadmap

Busbarless solar cells with multi-wire interconnection



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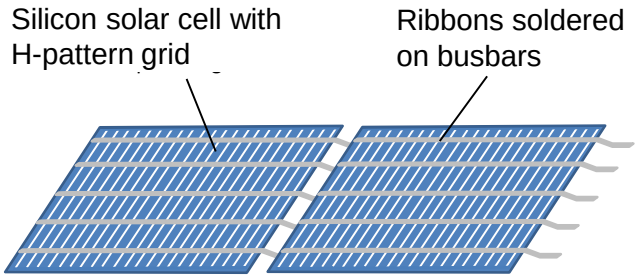
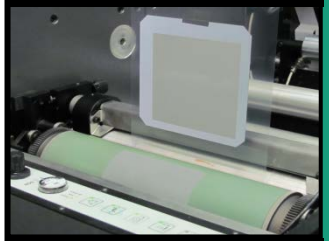
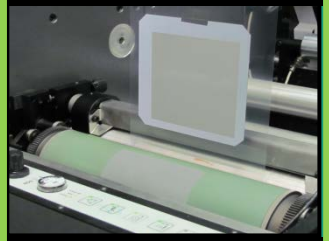


Rear Side Al



Rot. Screen Printing

Front Busbars

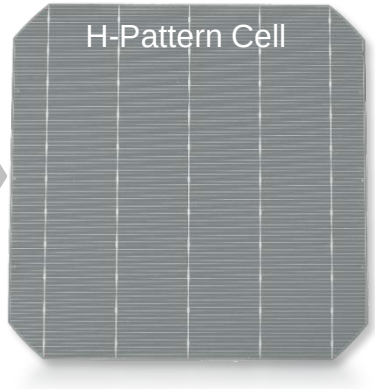


Rot. Screen Printing

Front Fingers

Dispensing

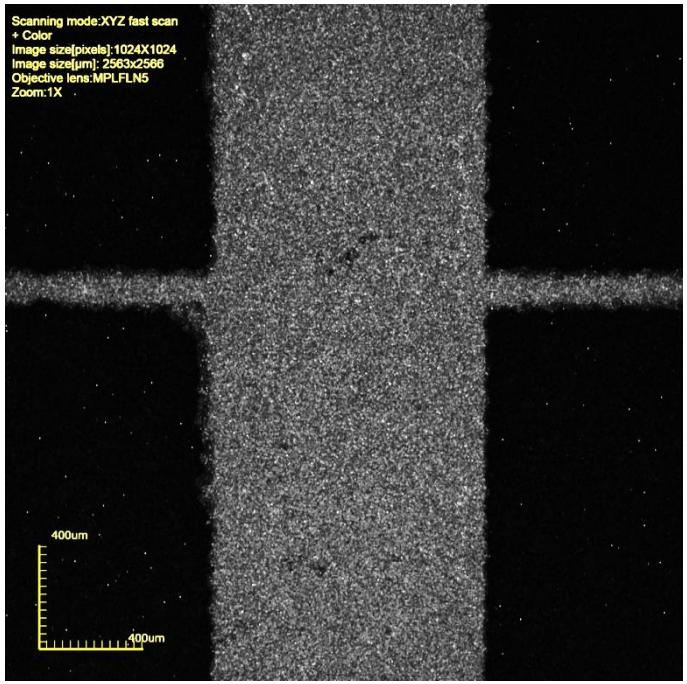
H-Pattern Cell



Experimental Results

Front side metallization using rotary screen printing

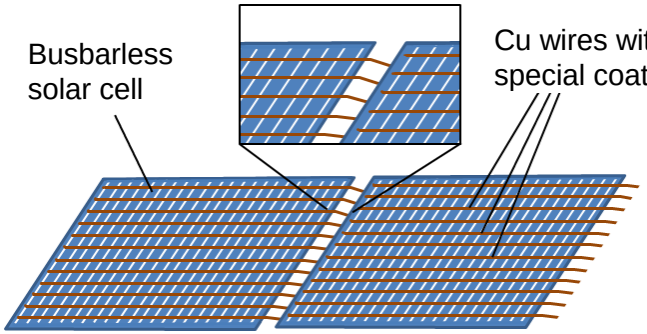
- Successful proof of principle for busbar printing
- Slightly diluted Ag paste
- Lines down to w = 100 µm can be printed with good quality
- Further development: Adaption of paste for fine line finger printing



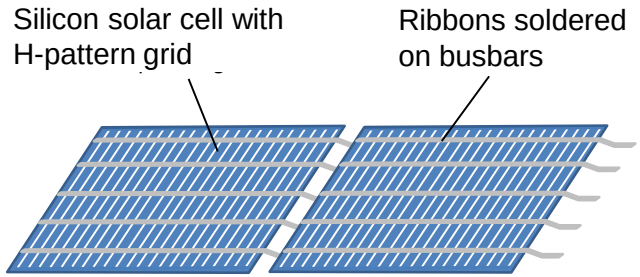
CLSM-Image of a standard busbar with a nominal width of w_B = 1,0 mm printed with rotary screen printing

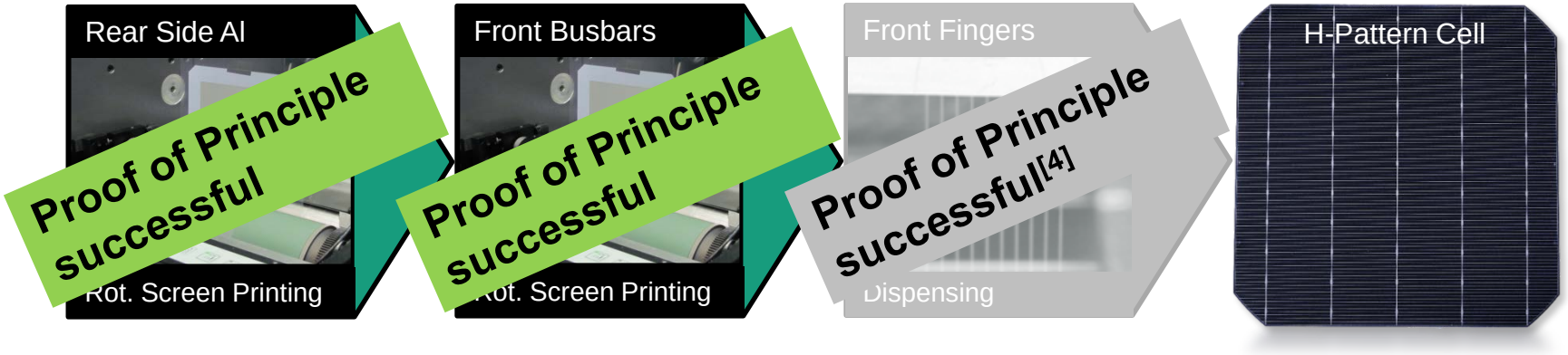
Motivation
Roadmap

Busbarless solar cells with multi-wire interconnection



H-pattern solar cells with soldered ribbons





[4] Pospischil et al., 6th Metallization Workshop (2016)

Rotary Screen Printing for Silicon Solar Cells
Summary + Outlook

Experimental results:

- Successful proof of principle:
  - RSP rear side metallization
  - RSP busbar printing
- I-V-results on the same level as FSP reference solar cells

Challenges and further research:

- Optimization of paste rheology
- Possible application for front side metallization
- Combination with flexographic printing and parallel dispensing
- Proof of concept with respect to an industrial application

Rotary Screen Printing for Silicon Solar Cells

The „Rock-Star“ Demonstrator – Coming in 2018

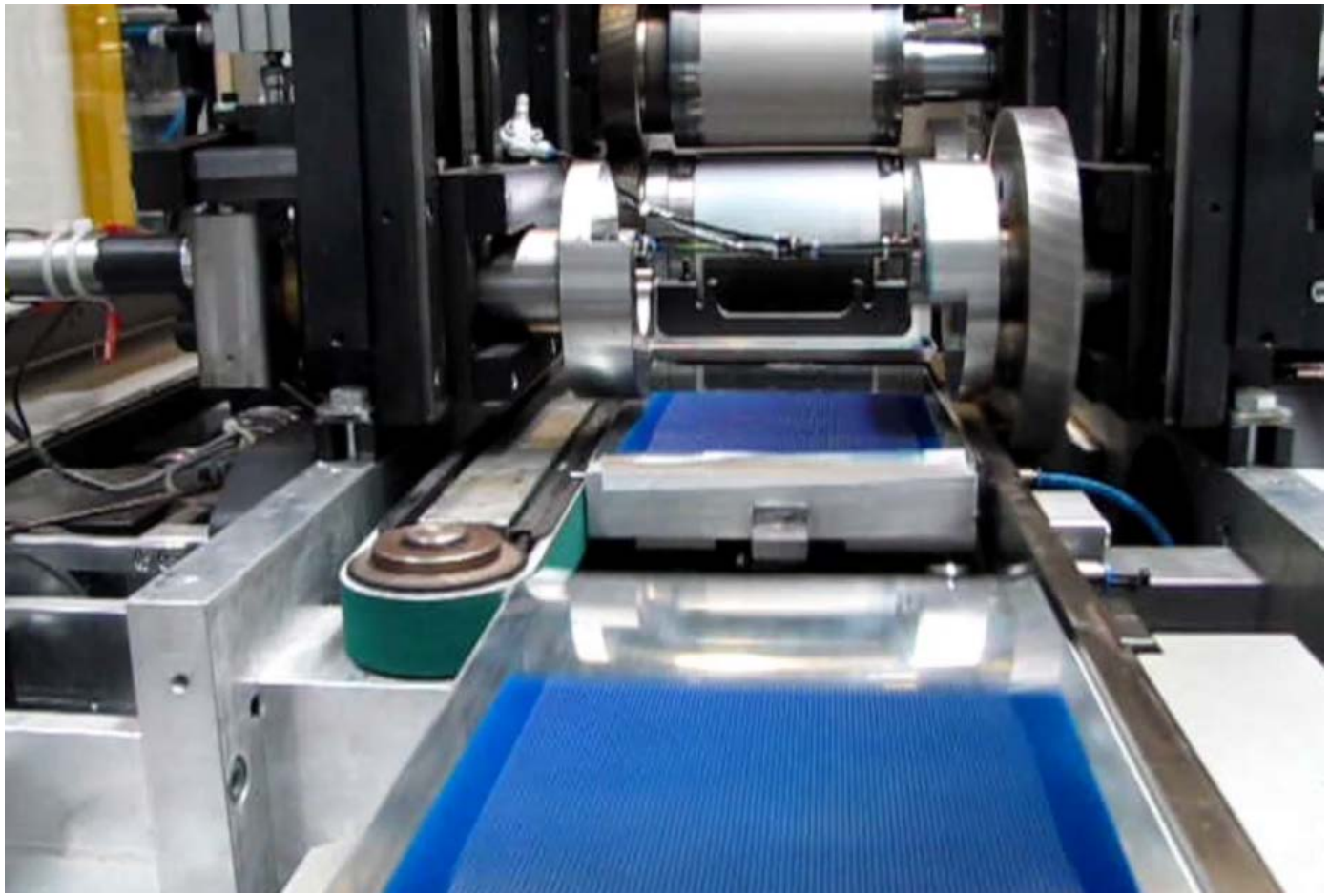


Image from flexo printing test at TU Darmstadt IDD

Rotary Screen Printing for Silicon Solar Cells
Relevant Publications

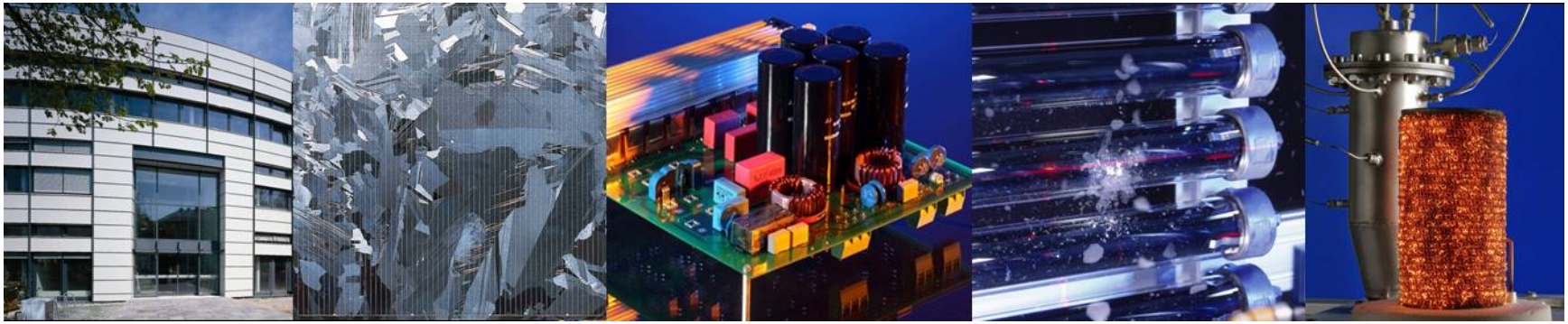
- **Article in PV International 37 (2017):**

  „Towards a high-throughput metallization for silicon solar cells using rotary-printing methods"

- **Poster and Paper on 7th SiliconPV (2017):**
  Lorenz A, Münzer A, Lehner M, Greutmann R, Brocker H, Reinecke H, Clement F, High-throughput front and rear side metallization of silicon solar cells using rotary screen printing. Energy Procedia 124, S. 680–690, doi: 10.1016/j.egypro.2017.09.343 (2017).

- **Oral Presentation and Paper on 33rd EUPVSEC (2017):**
  Clement A, Lorenz A, Pospischil M, Biro D, Brocker H, Bangel D, Greutmann R, Lehner M, Ott T, Hage F, Oppelt K, Honold T, Wende L, Ringel M, Senne A, Rohde J, Preu R, High Troughput printing for highly efficient cost-effective Si solar cells. Proc. of the 33rd EUPVSEC (2017)

Thank you for your attention!



… and all Co-workers at PVTEC
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