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

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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]

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]

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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

\(^2\) ITRPV Roadmap, 2017

Flexible printing plate with fine line front side grid layout
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:

Associated partners:

Gefördert von

aufgrund eines Beschlusses des Deutschen Bundestages
Motivation

Roadmap

Busbarless solar cells with multi-wire interconnection

- Busbarless solar cell
- Cu wires with special coating

H-pattern solar cells with soldered ribbons

- Silicon solar cell with H-pattern grid
- Ribbons soldered on busbars
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- **Rear Side AI**
  - Rot. Screen Printing

- **Front Fingers**
  - Flexo Printing

- **Busbarless Cell**
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Busbarless Cell

Proof of Principle successful\(^3\)

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**Process Steps**

1. **Rear Side Al**
   - Rot. Screen Printing
2. **Front Busbars**
   - Rot. Screen Printing
3. **Front Fingers**
   - Dispensing
4. **H-Pattern Cell**
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Proof of Principle successful[4]

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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 envisioned in 2000\(^6\)

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\[^5\] Datasheet Gallus ECS 340 (260)
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Approach
Rotary Screen Printing Technology (RSP)

- Difference to flatbed screen printing:
  - Continuous 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\textsuperscript{a} solar cells
- p-type Cz-Si Wafers (156 mm x 156 mm\textsuperscript{2})
- 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)

*Aluminium Back Surface Field*
Experimental Results
Comparison of rear side metallization

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

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\[^7\]
  \[
  t_{\text{eut}} = \frac{m_{\text{Al}}}{A \cdot \rho_{\text{Si}}} \cdot \frac{S_{\text{Si, melt}}(T_{\text{eut}})}{1 - S_{\text{Si, melt}}(T_{\text{eut}})}
  \]

- Depth of the Al-doped p+ Si region depends on initial mass of Al and effective peak set temperature\[^7\]
  \[
  t_{\text{Al-p}^+} = \frac{m_{\text{Al}}}{A \cdot \rho_{\text{Si}}} \left[ \frac{S_{\text{Si, melt}}(T_{\text{peak}})}{1 - S_{\text{Si, melt}}(T_{\text{peak}})} - \frac{S_{\text{Si, melt}}(T_{\text{eut}})}{1 - S_{\text{Si, melt}}(T_{\text{eut}})} \right]
  \]

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

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)

Experimental Results
Impact on $V_{oc}$ and $R_{SH,\text{rear}}$

- 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 $R_{SH,\text{rear}}$ acceptable for all groups

<table>
<thead>
<tr>
<th>Exp. Group</th>
<th>$R_{SH,\text{rear}}$ [m$\Omega$/sq.]</th>
<th>$\Delta\text{FF}_{\text{rear}}$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (RSP)</td>
<td>$19.7 \pm 0.5$</td>
<td>0.016</td>
</tr>
<tr>
<td>Group 2 (RSP)</td>
<td>$12.4 \pm 0.2$</td>
<td>0.010</td>
</tr>
<tr>
<td>Group 3 (RSP)</td>
<td>$4.3 \pm 0.1$</td>
<td>0.004</td>
</tr>
<tr>
<td>Group 4 (FSP)</td>
<td>$14.0 \pm 0.3$</td>
<td>0.011</td>
</tr>
</tbody>
</table>

*Normalized to a layer thickness of 25 µm
Experimental Results
I-V-Results of solar cells

- Groups 2 and 3 achieved comparable conversion efficiency to reference FSP group 4:
  - Group 2 (RSP): $\eta_0 = 19.4\%$
  - Group 3 (RSP): $\eta_0 = 19.3\%$
  - Group 4 (FSP): $\eta_0 = 19.3\%$

Conversion efficiency $\eta$ of the four experimental groups
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Rot. Screen Printing

Front Busbars

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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 $w = 100 \, \mu m$ 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
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Proof of Principle successful

- Rear Side Al
- Front Busbars

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):**

- **Oral Presentation and Paper on 33rd EUPVSEC (2017):**
Thank you for your attention!

… and all Co-workers at PVTEC
… as well as our industry partners who supported this work

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