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

A. Lorenz¹, M. Klawitter¹, M. Linse¹, M. Salimi¹, J. Reiner¹, K. Oehrle¹, S. Tepner¹, R. Greutmann², O. Vetter², J. Röth³, L. Sänger³, M. Drews³, K. Muramatsu⁴, S. Ikarashi⁴, F. Clement¹

¹Fraunhofer ISE, Freiburg, Germany
²Gallus Ferd. Rüesch AG, St. Gallen, Switzerland
³EKRA Automatisierungssysteme GmbH, Bönnigheim, Germany
⁴Namics Corporation, Japan

10th Metallization & Interconnection Workshop
Fraunhofer Institute for Solar Energy Systems ISE
Genk, 15.11.2021
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)*
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 resources: Current Ag consumption would require up to 90% of global production in 2030


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

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 resources: 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 $t \approx 1$ s
    - Further reduction difficult due to technical limitations (stop-and-go modus)

Rotary Printing for Solar Cell Metallization

Challenge

The Challenge:
»Reduce silver, boost production throughput but maintain the same quality level«
Rotary Printing for Solar Cell Metallization
»Rock-Star« Approach

Approach of project »Rock-It«: 
»Rotary and continous printing instead of flat and sequential printing«
Rotary Printing for Solar Cell Metallization

Agenda

1. Background & 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

Technical Background – Rotary Screen Printing Technology

- Cylinder-shaped screens
- Mounting of flat screen with gear rings
- Stainless steel meshes: ~64 – 400 wires/inch
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
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 $w_f \approx 40 \, \mu m$\[2\]
»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
Rotary Printing for Solar Cell Metallization

Agenda

1. Background & Motivation

2. Technology
   Rotary Screen Printing Technology

3. Experiment
   Experimental Setup and Results

4. Summary and Outlook
   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

<table>
<thead>
<tr>
<th>Group 1 (Rotary 40 µm)</th>
<th>Group 2 (Rotary 30 µm)</th>
<th>Group 3 (Reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial SHJ precursor incl. TCO (Bifacial)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rear side grid</td>
<td>Rear side grid</td>
<td>Rear side grid</td>
</tr>
<tr>
<td>Rotary SP, 150 finger</td>
<td>Rotary SP, 150 finger</td>
<td>Flatbed SP, 150 finger</td>
</tr>
<tr>
<td>( w_n = 30 ) µm</td>
<td>( w_n = 40 ) µm</td>
<td>( w_n = 40 ) µm</td>
</tr>
<tr>
<td>Drying &amp; Curing, ( T \approx 200°C, t \approx 10 ) min.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front Side Grid</td>
<td>Front Side Grid</td>
<td>Front Side Grid</td>
</tr>
<tr>
<td>Rotary SP, 80 finger</td>
<td>Rotary SP, 80 finger</td>
<td>Flatbed SP, 80 finger</td>
</tr>
<tr>
<td>( w_n = 30 ) µm</td>
<td>( w_n = 40 ) µm</td>
<td>( w_n = 40 ) µm</td>
</tr>
<tr>
<td>Drying &amp; Curing, ( T \approx 200°C, t \approx 10 ) min.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I-V-Characterization (GridTouch on industrial cell tester)</td>
<td>3D confocal microscopy of contacts + image analysis (Dash)</td>
<td>Scanning electron microscopy of contacts</td>
</tr>
</tbody>
</table>
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
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)
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 \( h_f \), cross-section area \( A_f \)

<table>
<thead>
<tr>
<th>Group</th>
<th>Method</th>
<th>Side</th>
<th>Nom. width ( w_n ) [( \mu m )]</th>
<th>( \phi ) Width ( w_f ) [( \mu m )]</th>
<th>( \phi ) Height ( h_f ) [( \mu m )]</th>
<th>( \phi ) Cross section area ( A_f ) [( \mu m^2 )]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rotary SP</td>
<td>FS</td>
<td>30</td>
<td>52 ± 3</td>
<td>5 ± 0.3</td>
<td>154 ± 12</td>
</tr>
<tr>
<td>2</td>
<td>Rotary SP</td>
<td>FS</td>
<td>40</td>
<td>53 ± 7</td>
<td>7 ± 0.4</td>
<td>201 ± 21</td>
</tr>
<tr>
<td>3</td>
<td>Flatbed SP</td>
<td>FS</td>
<td>40</td>
<td>47 ± 1</td>
<td>15 ± 0.6</td>
<td>386 ± 20</td>
</tr>
</tbody>
</table>
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
Rotary screen printed metallization of SHJ solar cells
Analysis of printing results

Published finger width for SHJ low-temperature paste

- Flatbed Screen Printing (Low-temperature paste)
- Rotary Screen Printing (LT Paste, This Publication)

Year of Publication

References:
## 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)

<table>
<thead>
<tr>
<th>Gr</th>
<th>Method</th>
<th>$W_n$ [µm]</th>
<th>Side</th>
<th>Wet Ag paste consumption Per Side [mg]</th>
<th>Total [mg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rotary SP</td>
<td>30</td>
<td>FS</td>
<td>11.3</td>
<td>37</td>
</tr>
<tr>
<td>1</td>
<td>Rotary SP</td>
<td>30</td>
<td>RS</td>
<td>26.1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Rotary SP</td>
<td>40</td>
<td>FS</td>
<td>13.5</td>
<td>47</td>
</tr>
<tr>
<td>2</td>
<td>Rotary SP</td>
<td>40</td>
<td>RS</td>
<td>33.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Flatbed SP</td>
<td>40</td>
<td>FS</td>
<td>40.8</td>
<td>116</td>
</tr>
<tr>
<td>3</td>
<td>Flatbed SP</td>
<td>40</td>
<td>RS</td>
<td>74.8</td>
<td></td>
</tr>
</tbody>
</table>

*wet paste (Printed pattern before drying/curing)*
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
Rotary screen printed metallization of SHJ solar cells

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%\textsubscript{abs} (40 µm grid) / ~70%\textsubscript{abs} (30 µm grid)
- Reduced finger height & cross section compared to flatbed screen printing

Rotary SP finger

- $w_f = 58 \, \mu m$
- $h_f = 10 \, \mu m$
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

<table>
<thead>
<tr>
<th>Gr.</th>
<th>Method</th>
<th>Grid w_n [µm]</th>
<th>Avg/Best</th>
<th>Jsc [mA/cm²]</th>
<th>Voc [mV]</th>
<th>FF [%]</th>
<th>η [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rotary SP</td>
<td>30</td>
<td>Avg</td>
<td>38.1</td>
<td>728</td>
<td>78.1</td>
<td>21.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Best Cell</td>
<td>38.0</td>
<td>730</td>
<td>78.6</td>
<td>21.8</td>
</tr>
<tr>
<td>2</td>
<td>Rotary SP</td>
<td>40</td>
<td>Avg</td>
<td>38.1</td>
<td>278</td>
<td>78.2</td>
<td>21.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Best Cell</td>
<td>38.3</td>
<td>730</td>
<td>79.1</td>
<td>21.8</td>
</tr>
<tr>
<td>3</td>
<td>Flatbed SP</td>
<td>40</td>
<td>Avg</td>
<td>38.2</td>
<td>729</td>
<td>78.8</td>
<td>22.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Best Cell</td>
<td>38.3</td>
<td>730</td>
<td>79.7</td>
<td>22.2</td>
</tr>
</tbody>
</table>
Rotary screen printed metallization of SHJ solar cells

Analysis of I-V-Results

I-V-Results:

- Conversion efficiency $\eta$ of RSP metallized cells around $\Delta \eta \sim 0.3\text{-}0.4 \%_{\text{abs}}$ 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)
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
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

Thank You!

Rotary Printing Project Team
Thank You for Your Attention!

Andreas Lorenz

www.ise.fraunhofer.de
Andreas.Lorenz@ise.fraunhofer.de