Advanced Metallization with Low Silver Consumption for Silicon Heterojunction Solar Cells

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Introduction
- Ag is a main cost driver in photovoltaics production [1]
- Metallization with Ag reduction potential for Silicon Heterojunction (SHJ) solar cells investigated
- Screen-printing of Ag-coated copper paste [2] ⇒ Pot. 30% Ag reduction
- Inkjet-printing of Ag nanoparticle ink [3] ⇒ > 90% Ag reduction
- FlexTrail-printing of Ag nanoparticle ink ⇒ > 90% Ag reduction

Inkjet-Printing of Ag Nanoparticle Ink

Dependence on the printed layer number per finger
- Busbarless SHJ solar cells
- Correction of PCB Touch [4] measurement necessary (see also Ref. [5]):
  - The lower the layer number the higher the \( j_{SC} \)
  - Highest FF with one/two printed layers (see explanation below)

Contacting extreme thin fingers with PCB Touch

<table>
<thead>
<tr>
<th>Printing technique</th>
<th>( V_{OC} ) (mV)</th>
<th>( j_{SC} ) (mA/cm²)</th>
<th>FF (%)</th>
<th>( \eta ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inkjet-printing (one layer)</td>
<td>733.8</td>
<td>36.7</td>
<td>81.6</td>
<td>23.1</td>
</tr>
<tr>
<td>Screen-printing</td>
<td>796.8</td>
<td>37.9</td>
<td>80.1</td>
<td>22.4</td>
</tr>
</tbody>
</table>

\( V \) data (median values) of busbarless SHJ solar cells with comparable grid layouts.

- \( R_L \) (screen-printing) < \( R_L \) (inkjet-printing)
- \( FF \) (screen-printing) < \( FF \) (inkjet-printing)

⇒ High fingers (e.g. screen-printing): PCB Touch contacts fingers only.
⇒ Thin fingers (e.g. inkjet-printing): PCB Touch contacts fingers and ITO.

Conclusion
- 21.6% median efficiency of bifacial five busbar SHJ solar cells achieved with screen-printed Ag-coated copper paste and silver paste
- 23.3% maximum efficiency of a busbarless bifacial SHJ solar cell utilizing a inkjet-printed front grid achieved
- FlexTrail-printing allows for 23.7% maximum efficiency of a busbarless bifacial SHJ solar cell

FlexTrail-Printing of Ag Nanoparticle Ink

- FlexTrail is established at Fraunhofer ISE as a novel printing technology
- Printing of commercially available Ag nanoparticle ink
- FlexTrail’s arguments:
  - Printing of ultra-fine lines, flexible layouts
  - Large process window, simple handling
  - Higher process stability compared with inkjet-printing (e.g. clogging)

Microscopy images at a magnification of 50 of an inkjet-printed finger (one layer) (left) and a FlexTrail-printed finger (right) on alkaline textured SHJ solar cells.

Screen-Printing of Silver-Coated Copper Paste

- 21.6% median efficiency achieved with pure Ag and Ag-coated copper
- \( V_{OC} \) on similar level for both groups (mean value is 734.4 ± 1.0 mV)
- Finger widths and finger resistances (40 µm screen openings):
  - Paste AgCu: 60 ± 2 µm and 2.1 ± 0.1 Ω/cm
  - Paste Ag: 49 ± 1 µm and 2.8 ± 0.3 Ω/cm

SEM images of an inkjet-printed one-layer-finger’s (left) and a screen-printed finger’s (right) cross-section.

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