Screen printable, non-fire-through copper paste applied as busbar metallization for back contact solar cells

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Motivation: ITRPV roadmap

- Silver is the most-expensive non-silicon material used in current c-Si technologies
- Either paste consumption has to be reduced or Ag has to be substituted by another material

![Trend for remaining silver for metallization per cell (front + rear side)](chart)

Values for 166.0 x 166.0 mm² cell size

Motivation: why copper?

• Silver price is extremely volatile: $783 /kg (10.11.2021)
  2020 ~ $580 /kg
• Copper is a great alternative

<table>
<thead>
<tr>
<th>Raw material comparison:</th>
<th>Silver</th>
<th>Copper</th>
<th>Copper vs Silver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price per kg</td>
<td>$783</td>
<td>$8</td>
<td>~100x cheaper</td>
</tr>
<tr>
<td>Conductivity</td>
<td>$1.59×10^{-8}$ Ωm</td>
<td>$1.68×10^{-8}$ Ωm</td>
<td>5% less conductive</td>
</tr>
<tr>
<td>Carbon footprint</td>
<td>155 kgCO$_2$/kg</td>
<td>3.97 kgCO$_2$/kg</td>
<td>40x better</td>
</tr>
<tr>
<td>Max level in drinking water (EPA)</td>
<td>0.1 mg/liter</td>
<td>1.3 mg/liter</td>
<td>10x less toxic</td>
</tr>
<tr>
<td>Abundance in Earth's crust</td>
<td>0.08 ppm</td>
<td>68 ppm</td>
<td>~1000x more abundant</td>
</tr>
</tbody>
</table>
**Motivation: n-type IBC Zebra metallization**

- In 3d-IBC Zebra metallization the amount of silver for cell production is even higher.
- CoO for a cell can be reduced by 13% if only the Ag busbars are replaced by Cu.
- Further CoO reduction of 6% by replacing also finger metallization with Cu.

- 5 GWp/year factory located in Europe.
- Ag-price: 783 USD/kg.
- Cu paste price: 50% of Ag-paste price.
- Depreciation periods (Process equipment 5 y, Facilities: 10 y, Building: 20 y).
Main requirements for Cu based metallization

- High throughput process capability
- Solderability
- **No contamination** of the cell
- Series resistance
- Adhesion
- Long time durability and reliability
Experimental setup

• N-type IBC cells without metallization directly taken from the production

• Metallization carried out until BB, using standard Ag and isolation paste

• Busbars print:
  • G1: low temperature Ag paste
  • G2: Cu paste LF371, laydown 76% of Ag
  • G3: Cu paste LF390, laydown 61% of Ag
  • G4: Cu paste LF370, laydown 47% of Ag

• Drying at 100°C + sintering at 300°C for 5 seconds (Cu pastes)

• IV measurement, line resistance, soldering, peel force, mini modules, climate chamber tests
Results cell IV characteristic

- Hardly any influence on $J_{SC}$ and $V_{OC}$
- Increased FF due to lower series resistance of samples with Cu paste
  → slightly improved cell efficiency
Peel force results: soldering and ECA

• Peel force of soldered ribbons on Cu BB is 0-0.8 N/mm
• Adhesion between ribbon and Cu paste is higher than between Cu paste and cell surface
• Peel force is significantly improved for G2 when using ECA → ribbons of the mini modules were glued by ECA
  → Adhesion of the paste on the cell surface is crucial and needs to be improved
Climate chamber tests

- Main motivation: rule out Cu penetration
- Half cell mini modules, ribbons connected via ECA
  - ECA was used instead of soldering to improve adhesion
- Front glass, rear back sheet with EVA as encapsulate
  - Worst case scenario as this combination is reactive and permeable
- TC up to TC600
- DH up to DH3000
- IV and EL after TC100, 200, 400 and 600 as well as DH500, 1000, 2000 and 3000
Thermal cycling results

- $V_{OC}$ and pFF do not change significantly $\rightarrow$ no Cu indiffusion
Thermal cycling results

- Reason for FF drop: Contact between Cu & Ag paste or between ribbon and Cu paste

![EL G2 TC100](Image)
![EL G2 TC200](Image)
![EL G2 TC400](Image)
![EL G2 TC600](Image)

![EL G4 TC100](Image)
![EL G4 TC200](Image)
![EL G4 TC400](Image)
![EL G4 TC600](Image)

![Graph showing Relative FF change vs Climate chamber Test](Image)
Thermal cycling results

- All tested modules passed TC 200 (1xIEC)
- Two modules of G4 passed TC400
Damp heat results

- Up to DH 3000 all modules survived the test cycles with a max power drop of 3.8%
- Important: pFF shows no degradation → no Cu indiffusion
- FF is reduced due to the same issue observed after TC
Damp heat results

• Surface of the Cu paste is obviously oxidized → darker colour

• As the FF drop is moderate an oxidation underneath the ribbon seems unlikely

*images taken through back sheet & EVA layer
Line resistance Cu busbars

- Line resistance measured by 4-point probe
- Busbar width 1.5 mm, height ≈12 µm
- All three Cu pastes are comparable to the silver reference G1
- With paste LF 390 (G3) the lowest line resistance of 0.032 Ω/cm is obtained → ρ ≈ 5.76 \times 10^{-8} \text{ Ωm} \text{ (pure Cu:}1.68 \times 10^{-8} \text{ Ωm)}
Requirements fulfilled

- High throughput process capability
- Solderability
- **No contamination** of the cell
- Series resistance
- Adhesion
- Long time durability and reliability

- Screen printing & short drying/curing
- Stringer
- pFF & Climate chamber tests
- Line resistance & FF
- Peel force
- Climate chamber tests
Conclusion

• Cu paste from Copprint Ltd. can be a valid replacement for silver busbar paste in n-type ZEBRA IBC solar cells

• IV characteristics and line conductivity are comparable to cells made with Ag BB

• Peel force tests made after soldering are low compared to Ag busbar, while ECA glued samples reached better values

• Weak adhesion between Cu paste and substrate is the main reason

• After 3 times IEC DH and TC modules show no pFF degradation
  → Cu indiffusion is no issue
Outlook – full Cu metallized cell

- First cells with only **25 mg silver** per cell were made
- Cu pastes and used screens are not yet optimized!
- Very promising results with high $V_{OC}$ and $pFF$ values

<table>
<thead>
<tr>
<th></th>
<th>Jsc</th>
<th>Voc</th>
<th>FF</th>
<th>Eta</th>
<th>SunsVoc</th>
<th>pFF</th>
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</thead>
<tbody>
<tr>
<td><strong>Cu finger&amp;BB</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Best cell</td>
<td>41.24</td>
<td>0.6894</td>
<td>78.37</td>
<td>22.28</td>
<td>0.6892</td>
<td>82.63</td>
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<td>Average</td>
<td>41.18</td>
<td>0.6891</td>
<td>77.75</td>
<td>22.06</td>
<td>0.6889</td>
<td>82.65</td>
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<tr>
<td>Std. dev.</td>
<td>0.04</td>
<td>0.0004</td>
<td>1.04</td>
<td>0.31</td>
<td>0.0005</td>
<td>0.16</td>
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<td><strong>Reference_Ag finger&amp;B</strong></td>
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<td>82.62</td>
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<tr>
<td>Std. dev.</td>
<td>0.05</td>
<td>0.0011</td>
<td>1.49</td>
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<td>0.0011</td>
<td>0.44</td>
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</tbody>
</table>
Acknowledgements

Thank you for your attention

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