Reliable double printing of Ag contacts for c-Si cell manufacturing

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Outline

1. Double Printing principle
2. Experimental results of DP wafers processed at Baccini lab and Helios production
3. Experimental results of DP in production
Double Printing vs. Single Printing

- SP and DP cell design

- Target: reduce finger width and increase finger thickness
- Standard up-front process flow
- Compatible with existing production lines (3 + 1 printers)

- $I_{sc} \uparrow \uparrow$, $R_s=\approx$, $FF=\approx$, $\eta \uparrow \uparrow$

B. Raabe et al, 20°EUPVSEC Barcelona 2005
DP Simulation

- Screen design optimization model inputs
  - Finger width/thickness, nr
  - Emitter Rsheet
  - Paste conductivity
  - Contact resistance

- Output eff, FF, Isc

- Model predicts 0.27/0.3 abs eff increase from SP with 110um/15um to DP with 80um/25um depending on finger nr

- Finger width ↓↓, thickness↑↑, more fingers required to keep same FF and eff
DP test 1

- Test 90 cells/lot
- 3 busbars
- SP 69 finger, 80um std mesh screen opening, paste A
- DP 65 finger, 80um+80um Esatto Technology® qualified screen, paste A+A
- 0.12 abs eff increase
- -9% paste for DP
- Model exp 0.115 abs eff increase for DP

### Table: SP vs. DP design 1

<table>
<thead>
<tr>
<th></th>
<th>width (um)</th>
<th>thickness (um)</th>
<th>aspect ratio</th>
<th>weight (mg)</th>
<th>Pmpp (W)</th>
<th>Umpp (V)</th>
<th>Imp (A)</th>
<th>Uoc (V)</th>
<th>Isc (A)</th>
<th>Rs (mOhm)</th>
<th>Rsh (Ohm)</th>
<th>FF (%)</th>
<th>eta</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP paste A</td>
<td>109.1</td>
<td>27.7</td>
<td>0.25</td>
<td>212.0</td>
<td>3.896</td>
<td>0.519</td>
<td>7.505</td>
<td>0.619</td>
<td>8.003</td>
<td>0.0025</td>
<td>122.6609</td>
<td>78.69</td>
<td>16.01</td>
</tr>
<tr>
<td>DP paste A+A</td>
<td>95.7</td>
<td>38.5</td>
<td>0.40</td>
<td>193.0</td>
<td>3.925</td>
<td>0.518</td>
<td>7.575</td>
<td>0.620</td>
<td>8.075</td>
<td>0.0027</td>
<td>114.5429</td>
<td>78.44</td>
<td>16.13</td>
</tr>
<tr>
<td>difference</td>
<td>-13.4</td>
<td>10.8</td>
<td>0.15</td>
<td>-19.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.3</td>
<td>0.12</td>
</tr>
</tbody>
</table>
DP test 2 – Optimized screen design

- 3 busbars screen design
- 65Ohm/sq emitter

- Group 1: SP 69 fingers, 80um std mesh screen, **paste A**
- Group 2: DP 69 fingers, 60um+50um Esatto Technology qualified screen, **paste B+B**
- Group 3: DP 69 fingers, 60um+60um Esatto Technology qualified screen, **paste A+A**

1) 80um

2) 50um
   60um

3) 60um
   60um

156mm multi wafers - Helios
Texturing - Helios
POCI diffusion - Helios
PSG etch - Helios
SiN ARC - Helios
Front side DP – BCS lab
Back side print - Helios
Firing - Helios
Laser isolation - Helios
Testing – Fraunhofer ISE
DP test 2 – Contact resistance

<table>
<thead>
<tr>
<th>TLM sample 1</th>
<th>8597046 TLM sample 1</th>
<th>8597124 TLM sample 1</th>
<th>8618630 TLM sample 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rsh [Ω/sq]</td>
<td>62.4937</td>
<td>67.7446</td>
<td>66.5400</td>
</tr>
<tr>
<td>$\rho_c$ [Ωcm$^2$]</td>
<td>0.0013</td>
<td>0.0023</td>
<td>0.0025</td>
</tr>
<tr>
<td>Rc [Ω]</td>
<td>0.2902</td>
<td>0.4885</td>
<td>0.6957</td>
</tr>
<tr>
<td>Rcw [Ωcm]</td>
<td>0.2902</td>
<td>0.4885</td>
<td>0.6957</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TLM sample 2</th>
<th>8597046 TLM sample 2</th>
<th>8597124 TLM sample 2</th>
<th>8618630 TLM sample 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rsh [Ω/sq]</td>
<td>63.4412</td>
<td>65.6175</td>
<td>63.5825</td>
</tr>
<tr>
<td>$\rho_c$ [Ωcm$^2$]</td>
<td>0.0028</td>
<td>0.0030</td>
<td>0.0030</td>
</tr>
<tr>
<td>Rc [Ω]</td>
<td>0.6521</td>
<td>0.8339</td>
<td>0.7852</td>
</tr>
<tr>
<td>Rcw [Ωcm]</td>
<td>0.6521</td>
<td>0.8339</td>
<td>0.7852</td>
</tr>
</tbody>
</table>

### Group 1
- $\rho_c = 2 \pm 0.8$ mΩcm$^2$
- TLM contact resistance analysis performed on 2 cells of each group
- Low difference in $\rho_c$ values between groups (due to different finger widths)
- Group 1 shows lowest contact resistance $R_C$
- Group 1 shows lowest specific contact resistance $\rho_c$

### Group 2
- $\rho_c = 2.6 \pm 0.3$ mΩcm$^2$

### Group 3
- $\rho_c = 2.8 \pm 0.3$ mΩcm$^2$
DP test 2 – CoRRescan map

**Group 1:**
- High quality of contact/emitter
- Homogeneous and low potential drop
- Average potential drop: 4 mV
- Maximum potential drop: 44.4 mV

**Group 2:**
- Medium/low quality of contact/emitter
- Rather inhomogeneous potential map
- High local potential drops
- Average potential drop: 7.1 mV
- Maximum potential drop: 50.3 mV

**Group 3:**
- Medium quality of contact/emitter
- Homogeneous potential drop
- Very high local potential drop (corner)
- Average potential: 6.2 mV
- Maximum potential: 152.3 mV
DP Test 2 - $R_s$-PL Measurements

**Group 1:**
- Rather homogeneous
- Some finger interruptions
- Edge effects visible

**Group 2:**
- Inhomogenous appearance
- Firing belt visible
- Right side of wafers higher resistance
- Edge effects visible

**Group 3:**
- More Inhomogeneous apperance than 2
- Firing belt visible
- No clear side effects visible
- Edge effects visible
DP test 2 – Finger morphology

<table>
<thead>
<tr>
<th>Group</th>
<th>Wafer</th>
<th>Final Dried Print</th>
<th>Width (um)</th>
<th>Thickness (um)</th>
<th>Aspect Ratio</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>91,8</td>
<td>21,6</td>
<td>0,24</td>
<td>0,185</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>76,3</td>
<td>23</td>
<td>0,30</td>
<td>0,17</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>74,7</td>
<td>26,9</td>
<td>0,36</td>
<td>0,16</td>
</tr>
</tbody>
</table>

Group 2: -8% paste consumption
Group 3: -14% paste consumption
**DP test 2 – Electrical data**

![Graphs showing electrical data](image)

### Table: Electrical Data

<table>
<thead>
<tr>
<th>Cell group</th>
<th>Voc</th>
<th>Jsc</th>
<th>Eta</th>
<th>FF</th>
<th>SserL/Df/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[mV]</td>
<td>[mA/cm²]</td>
<td>[%]</td>
<td>[%]</td>
<td>[Ω·cm²]</td>
</tr>
<tr>
<td>1</td>
<td>614.3</td>
<td>33.95</td>
<td>16.34</td>
<td>78.34</td>
<td>0.63</td>
</tr>
<tr>
<td>2</td>
<td>617.6</td>
<td>34.34</td>
<td>16.57</td>
<td>78.14</td>
<td>0.72</td>
</tr>
<tr>
<td>3</td>
<td>615.8</td>
<td>34.53</td>
<td>16.56</td>
<td>77.88</td>
<td>0.76</td>
</tr>
</tbody>
</table>

**Remarks:**

- **Jsc +0.4/0.5mA/cm² - reduced shading**
- **FF -0.2/-0.5% - reduced Rs**
- **Voc +1.5/3mV – reduced contact area and J₀**

Measured @ Fraunhofer ISE
DP test 2 – Results

- ...starting from an aggressive finger geometry for single printing baseline (92um x 22um, aspect ratio 0.26)
- ...achieved an aspect ratio in DP of 0.3-0.36
- Group 2: 0.23% eff increase with -8% paste
- Group 3: 0.22% eff increase with -14% paste
- Other customer demos at BCS lab show eff increase between 0.2% and 0.35%

- Developments
  - Demonstrated aspect ratio in DP of 0.5 (35um x 70um)
  - Create cells with this finger geometry for improved eff gain

- From the LAB to the FAB...
DP production – 12” screen

- 12”, 90um + 90um Esatto Technology qualified screens
- 125mm, mono wafers
- Commercial paste for SP
- 20k prints (1 day)
- Avg 0.2-0.25% eff increase for DP
- Optimized print process
DP production – 15” screen

- 15”, 90um + 90um Esatto Technology qualified screens
- 125mm mono wafers
- Commercial paste for SP (not optimized)
- Production monitor 105k cells (4 continuative days)
- Check for screen deformation/wear leading to misalignment
- Screen change when avg finger width for DP exceeds 125um or mechanical breakage
- Optimized print process
Conclusion / Next steps

- Demonstrated **0.23% abs eff increase for DP** with significant paste saving using Esatto Technology qualified consumables (starting from an aggressive SP baseline)
- Consistent agreement between simulation and experimental data
- Further optimization leads to **>0.3% abs eff increase** (already achieved with customer demos)
- LAB results already transferred successfully to the **production floor**
- Achieved high **screen stability** under optimized printing conditions
- Available **inline process monitoring and closed loop operation**

- **Paste optimization**, especially for high conductivity layer
- Demonstrate benefit of **DP at module level**
- Testing **fine line DP cells** (35um x 60-70um)
- Demonstrate **DP over Selective Emitter** with Esatto Technology
Thanks for your attention!

Dec ‘09

think it. apply it.

March ‘10