Reliable Metallization Process for Ultra Fine Line Printing

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Outline

- Industry Roadmap For Metallization: Overview
- Challenges Of Fineline Printing
- Ultra Fineline Double Printing: Results
- Double Printing In Mass Production: Customer Case
ITRPV Roadmap March 2013

Finger Width

Constant decrease in finger width and paste deposit as predictive trends
Fine Line Single Print Test

Standard SP

45µm screen opening
70µm printed finger width

Fine Line SP

35µm screen opening
Calendered screen
<60µm printed finger width

Apparently FLSP represents the most effective solution
Drawbacks of FLSP – Peel Force

**Standard SP**

**Fine Line SP**

![Graph showing peel force and height for Standard SP and Fine Line SP](image)

- **Peel Force**
  - Standard SP: 3.2 N
  - Fine Line SP: 0.7 N

- **Height**
  - Standard SP: 9 µm
  - Fine Line SP: 5 µm

**Legend**

- Green bar: Peel force
- Blue line: Height
Drawbacks of FLSP – Electroluminescence

Standard SP
Grid resistance = 30.5 mΩ
FF = 78.8%
Rs = 2.6 mΩ

Fine Line SP
Grid resistance = 45.9 mΩ
FF = 77.6%
Rs = 3.1 mΩ

Increasing number of finger breaks in the FLSP case
Process Limits of Screen Printing

- **Standard Printing**
  - Finger lines > 60µm
  - Recommended processes: Single Print, Double Print, Dual Print

- **Fine Line Printing**
  - Finger lines < 60µm
  - Recommended processes: Double Print

- **Ultra Fine Line Printing**
  - Finger lines < 50µm
  - Recommended processes: Double Print

Double Printing represents the recommended process to push the limits of screen printing in terms of:
- Fine Line capability
- Reduced number of finger breaks
- Possibility to use an optimized paste for BB printing
Introducing Ultra Fine Line DP

- Ion-implanted mono wafers from Applied Solion® Ion Implanter
- Paste A optimized for better contact properties
- Paste B designed for high adhesion

<table>
<thead>
<tr>
<th>Process</th>
<th>Screen Opening (µm)</th>
<th>Screen Mesh</th>
<th>Screen Opening (µm)</th>
<th># of fingers</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP</td>
<td>Paste A</td>
<td>290-20</td>
<td>45</td>
<td>78</td>
</tr>
<tr>
<td>Fine Line DPI</td>
<td>Paste A + Paste A</td>
<td>290-20</td>
<td>35+35</td>
<td>78</td>
</tr>
<tr>
<td>Fine Line DPII</td>
<td>Paste A + Paste B</td>
<td>290-20</td>
<td>35+35</td>
<td>78</td>
</tr>
<tr>
<td>Ultra Fine Line DPII</td>
<td>Paste A + Paste B</td>
<td>360-16</td>
<td>30+25</td>
<td>90</td>
</tr>
</tbody>
</table>
Morphology Data Comparison

<table>
<thead>
<tr>
<th>Paste Type</th>
<th>Finger Width (µm)</th>
<th>Laydown (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP Paste A</td>
<td>SP 45µm</td>
<td>102mg</td>
</tr>
<tr>
<td>FL DPI</td>
<td>DPI 35µm</td>
<td>126mg</td>
</tr>
<tr>
<td>FL DPII</td>
<td>DPII 35µm</td>
<td>126mg</td>
</tr>
<tr>
<td>Ultra FL DPII Paste A + Paste B</td>
<td>DPII 30+25µm</td>
<td>126mg</td>
</tr>
</tbody>
</table>

Ultra FLDP vs SP

47µm vs 63µm

102mg vs 126mg
# Electrical Data Comparison

<table>
<thead>
<tr>
<th>Process</th>
<th>Screen Opening (µm)</th>
<th>Width (µm)</th>
<th>Height (µm)</th>
<th>cross section (µm²)</th>
<th>Laydown (mg)</th>
<th>Voc (mV)</th>
<th>Isc (A)</th>
<th>FF (%)</th>
<th>Rs (mΩ)</th>
<th>CE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP</td>
<td>45</td>
<td>63</td>
<td>15</td>
<td>635</td>
<td>126</td>
<td>641</td>
<td>9.03</td>
<td>78.53</td>
<td>2.4</td>
<td>19.01</td>
</tr>
<tr>
<td>Fine Line DPI</td>
<td>35 + 35</td>
<td>56</td>
<td>21</td>
<td>559</td>
<td>119</td>
<td>643</td>
<td>9.11</td>
<td>78.61</td>
<td>2.1</td>
<td>19.27</td>
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<tr>
<td>Fine Line DPII</td>
<td>35 + 35</td>
<td>55</td>
<td>22</td>
<td>602</td>
<td>112</td>
<td>642</td>
<td>9.09</td>
<td>78.48</td>
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<tr>
<td>Ultra Fine Line DPII</td>
<td>30 + 25</td>
<td>47</td>
<td>21</td>
<td>405</td>
<td>102</td>
<td>642</td>
<td>9.12</td>
<td>78.27</td>
<td>2.3</td>
<td>19.19</td>
</tr>
</tbody>
</table>

**CE vs laydown**

Ultra FLDP vs SP
+0.18% CE
19% paste saving
Peel Force Advantage for DPII

DPI\textsubscript{35} vs. DPII\textsubscript{35}: similar BB height, higher peel force for paste B
### Customer Case: Double Printing*

<table>
<thead>
<tr>
<th>Width [µm]</th>
<th>Height [µm]</th>
<th>laydown [mg]</th>
<th>Voc [mV]</th>
<th>Isc [A]</th>
<th>FF [%]</th>
<th>Rs [mΩ]</th>
<th>CE [%]</th>
<th>ΔCE [%]</th>
<th># cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP</td>
<td>68</td>
<td>18</td>
<td>118</td>
<td>625</td>
<td>8.45</td>
<td>79.36</td>
<td>1.87</td>
<td>17.23</td>
<td>0</td>
</tr>
<tr>
<td>DP</td>
<td>59</td>
<td>22</td>
<td>98</td>
<td>624</td>
<td>8.53</td>
<td>79.50</td>
<td>1.88</td>
<td>17.40</td>
<td>0.17</td>
</tr>
</tbody>
</table>

- +0.17% efficiency gain and 20mg paste saving
- DP efficiency gain mainly related to higher Isc and FF

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*Enabled by Esatto Technology™
Higher production yield for DP associated to better metallization process, reducing efficiency tails

If cutoff is set at 16%, yield improvement is 0.2% in the DP case
Lifetime of DP Screens

Screen Test Evolution

- 290-20 combination screens
- 15” frame size
- Ultra-calendered mesh
- Screens lifetime: 35000 wafers with multiple runs

Run 1: Efficiency

Efficiency (%)

15 15.5 16 16.5 17 17.5 18 18.5

1 10001 20001 30001

Wafer

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Conclusions

- FLSP process limited by peel force and EL, not proven in mass production
- Demonstrated reduction of Ag laydown by 20% and CE increase of 0.18% with Ultra Fine Line DP
- Adjusting paste rheology guarantees high adhesion even for low deposit on busbar area
- Customer production data proves double printing robust process for fine line printing

Acknowledgements: