APPLICATION REQUIREMENTS FOR ELECTRICALLY CONDUCTIVE ADHESIVES AS INTERCONNECT MATERIALS FOR SHINGLED SOLAR CELLS

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Who is Henkel?
The Largest Adhesives Supplier in the World

- Henkel subsidiaries working on **Electrically Conductive Adhesives** (ECA’s) since the 1950’s and selling them for > 10 years for photovoltaic applications
- One of the largest **low temperature conductive silver paste suppliers**
- > €20B turnover, 47% in Adhesives Technologies
- 170 manufacturing sites and 21 major R&D centers around the world
Electronic Adhesive Technologies
Expertise in customizing highly filled polymeric systems

- Typically we focus on **highly customized materials** for key applications and customers
- Very broad portfolio of chemistries expertise: **Epoxy, Acrylate, Silicone, Bismaleimide** and **Hybrid**.
- **Over 30% of sales come from products launched within the last 5 years.**
- **Over 500 commercial ECA’s** and the largest market share globally.
Shingled Module Technology

Introduction

Optimized active area by tighter cell packing

Roadmap towards reduced overlap

Conventional Module:
c-Si Cell interconnect in series by solder (SnPb) coated copper ribbon

Shingled Module:
c-Si cell interconnect of shingles and ribbons by Electrically Conductive Adhesive (ECA)
Electrically conductive adhesive (ECA)

- A continuous network of particles is needed to ensure conductivity
  - High amount of contact points are needed
  - Network needs to be created before the end of cure
- Conductive filler determines viscosity/thixotropy of the material -> important for the application
- Polymer (acrylic, silicone, epoxy) determines mechanical property

Low silver loading ECA possible
Shingle overlap
Roadmap towards reduced overlap

Correct **ECA rheology**, **ECA application equipment** (ECA position accuracy and dimension) and **shingle tool** (placement accuracy) required in order to avoid ECA squeeze out both on front side and back side of cell.

Reduced overlap: 1,8 mm -> 1,4/1,5 mm -> 0,9/1,0 mm -> 0,6 mm

**TODAY**
Effect of rheology of ECA

- **Viscosity and shear thinning index**
  - Low viscosity: ECA flows more easily
  - High shear thinning: low viscosity upon application, high viscosity at rest
- **Thixotropy** (recovery rate)
- **Yield stress** (minimum stress required to get material to flow)

<table>
<thead>
<tr>
<th>Recovery rate</th>
<th>Yield stress</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low</strong></td>
<td></td>
</tr>
<tr>
<td>Slumping</td>
<td>Shingle top</td>
</tr>
<tr>
<td></td>
<td>Shingle bottom</td>
</tr>
<tr>
<td><strong>High</strong></td>
<td></td>
</tr>
<tr>
<td>Higher aspect ratio</td>
<td>Shingle top</td>
</tr>
<tr>
<td></td>
<td>Shingle bottom</td>
</tr>
</tbody>
</table>
Effect of ECA deposition location

Squeeze out

No ECA squeeze out at 0,8 mm overlap

Correct print location is needed in order to avoid squeeze out of the ECA after shingling

ECA squeeze out along the finger

Back of cell
Front side of cell

ECA squeeze out front side
Application Techniques

Printing versus dispensing

Courtesy of Applied Materials
Dispensing techniques
Jet versus time pressure dispensing

- **Jetting technology**: fast (400 mm/sec) – **limited line width** and requires **good maintenance of tool** for reproducible results
- **Time pressure**: **200 mm/sec possible** - demonstrated line widths of 100 microns in non-solar markets

<table>
<thead>
<tr>
<th>Adhesive Application</th>
<th>Time Pressure</th>
<th>Piezo Jet (150um)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line/dot width/diameter (micron)</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Robot speed (mm/sec)</td>
<td>80</td>
<td>200</td>
</tr>
</tbody>
</table>

Too wide for 0,6 mm overlap
### Dispensing result

<table>
<thead>
<tr>
<th>Items</th>
<th>ECA 3</th>
<th>ECA 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nozzle (Φ, mm)</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Tappet (Φ, mm)</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Pressure (MPa)</td>
<td>0.32</td>
<td>0.4</td>
</tr>
<tr>
<td>Falling time (ms)</td>
<td>0.15</td>
<td>0.18</td>
</tr>
<tr>
<td>Open time (ms)</td>
<td>2.0</td>
<td>2.3</td>
</tr>
<tr>
<td>Speed (mm/s)</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>ECA (cure before overlap)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width (um)</td>
<td>632-663</td>
<td>700-707</td>
</tr>
<tr>
<td>Height (um)</td>
<td>149-157</td>
<td>127-133</td>
</tr>
<tr>
<td>Distance between dots (um)</td>
<td>660-720</td>
<td>713-737</td>
</tr>
<tr>
<td>ECA (cure after overlap)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width (um)</td>
<td>825-940</td>
<td>959-1000</td>
</tr>
<tr>
<td>Height (um)</td>
<td>42-47</td>
<td>34-44</td>
</tr>
</tbody>
</table>

High jet speeds of 300 mm/s possible with nozzle diameter of 200 micron to enable a 1,4 mm shingle overlap
Printing techniques
Screen versus stencil printing

- **Stencil printing:** contact method, well known for electrically conductive adhesives

- **Screen printing:** contact less method, well established into the solar market (cell metallization paste)

<table>
<thead>
<tr>
<th></th>
<th>stencil</th>
<th></th>
<th></th>
<th>screen</th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>200 µm</td>
<td>300 µm</td>
<td>400 µm</td>
<td>200 µm</td>
<td>300 µm</td>
<td>400 µm</td>
<td></td>
</tr>
<tr>
<td>width (µm)</td>
<td>375</td>
<td>411</td>
<td>526</td>
<td>300</td>
<td>408</td>
<td>519</td>
<td></td>
</tr>
<tr>
<td>height (µm)</td>
<td>81</td>
<td>90</td>
<td>98</td>
<td>50</td>
<td>62</td>
<td>64</td>
<td></td>
</tr>
</tbody>
</table>

Higher aspect ratio and volume of ECA applied with stencil
**Stencil print** – 100 um thick stencil – 300 um opening

Height and width of ECA with different printing direction

- Higher height and wider width when using transversal printing direction.
**Stencil print** – 100 um thick stencil – 300 um opening

Height and width of ECA with different printing speed

- Narrow printing width of ECA when increasing the printing speed

Snap off: 600um
Stencil: 100um EOM/ 300um opening

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**Screen print – 200/40 SS, 18 µm EOM**

Height and width of ECA with different printing speed

- Print evaluation: Very fast speeds are possible
- Printed weight remains constant for all tested print speeds
Conclusions

• Shingle based modules have promising future for different cell technologies and modules produced with Henkel ECA shown good reliability passing IEC standards

• Henkel offers ECAs based on different chemistries (epoxy, acrylate, silicone based) with high application speeds (> 200 mm/sec) for both print and dispense methods

• In order to enable a small shingle overlap it’s important to have correct:
  • ECA rheology (viscosity, shear thinning, thixotropy, yield stress)
  • ECA application method (type, accuracy)
  • Shingle tool

• Shingled solar modules with 0,8 mm overlap were assembled by printing Henkel ECA without squeeze out after application optimization
Thank you!