MATERIALS CHALLENGE FOR SHINGLED CELLS
INTERCONNECTION

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Dow Corning

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Konstanz, 3 May 2016
Introduction to Dow Corning

• A global leader in silicones and high-purity silicon.
  – 7,000 products/services
  – 25,000 customers
  – Approx. 11,000 employees
  – $6.2 billion sales 2014

• Founded in 1943 to explore the potential of the silicon atom.

• Focus on innovation
  – 4-5% investment of sales in R&D
  – 5,066 active patents
<table>
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<th>Ownership of Dow Corning</th>
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<tr>
<td>1943 – 2016:</td>
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<tr>
<td><strong>Dow</strong> + <strong>CORNING</strong></td>
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<td>Equal ownership</td>
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<th>December 2015:</th>
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<tr>
<td>Dow Chemical announce intention to acquire 100% ownership of Dow Corning Corporation</td>
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<th>Q2 2016 onwards:</th>
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<td>Subject to regulatory approvals,</td>
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<tr>
<td>• Dow Corning to become part of Dow Chemical</td>
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<td>• Hemlock Semiconductor Group to remain with current shareholders</td>
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<td>• No change in commitment to provide our customers with high-quality, reliable silicone products</td>
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Traditional module technology based on H-pattern cells, ribbons and soldered interconnection

- Low-cost interconnection
- Robust and durable

- High shading losses
- Expensive metallization
- High resistive losses
- Incompatibility with very thin wafers
- Lead-containing solder
Alternative interconnection technologies

Conductive backsheet + Electrically Conductive Adhesive

- **Cells**: Back-contact cells (MWT or IBC)
- **Bulk interconnection material**: Copper foil
- **Joints**: ECA

Multiwire technology

- **Cells**: Busbarless cells
- **Bulk interconnection material**: Copper wires
- **Joints**: Low temperature solder

Shingled cells module

- **Cells**: Busbarless cells (strips)
- **Bulk interconnection material**: None
- **Joints**: ? Solder or ECA
Shingled cells interconnection

Front

Back

Interconnection

Top view

Cross-section

Interconnection material

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Shingled cells interconnection: advantage and history

- Extremely high ratio active area / total area
  - Potential for very high efficiency

- ‘Old’ idea:
  - Development for early space modules in USA in -60’s and -70’s
  - High efficiency panels for solar car race in -90’s
    - e.g. ‘20 000 PERL Silicon Cells for the 1996 World Solar Challenge Solar Car Race’, Zhao et al. Progress in Photovoltaics 1997

- Recent surge of interest for terrestrial modules
  - Step 1: Start-ups developed technology: Cogenra, Solaria, …
  - Step 2: Large PV companies acquiring technology and preparing for mass production: Sunpower ‘Performance series module’; Sunedison ‘Zero White Space module’, …
Thermomechanical challenge

- Thermal cycling of system with different materials
  - mechanical stress due to CTE mismatch

Traditional modules

- High T
- Low T

Shingled cells modules

- High T
- Low T
Material options

Materials for shingled cells interconnection

Solder
- SnPb solder
- Low T solder

Electrically conductive adhesive
- Epoxy based
- Acrylate based
- Silicone based

Chemical structures for different materials:

- SnPb solder
- Low T solder
- Epoxy based
- Acrylate based
- Silicone based
Silicone Electrically Conductive Adhesive

- *Dow Corning® PV-5802 Electrically Conductive Adhesive*: silicone-based ECA developed for advanced module assembly

- Thixotropic properties for stencil printing

- Low Ag content, yet high conductivity

- Compared to other ECAs: flexible, low modulus

- Compatible with various surfaces, including screen-printed Ag
Analytical study of shear stress in joints

Assumptions:

- Glass imposes its CTE-induced movement to other laminate components (Bennett et al., Energ. Proc. 2012) → also to shingled cells string

- No external shear force on string (simplifying assumption to get lower bound of maximum joint stress)

- All deformation located at joints, no cell buckling
Outcome of analytical study

Condition to avoid joint failure:

\[ G(\Delta T)\left\{ L_0 \alpha_{glass} - \alpha_{Si} n l_0 - (n - 1)w_0 \right\} < 1 \]

- Shear modulus of joint material
- Difference between stress-free temperature and lowest operating temperature
- Length of glass at stress-free temperature
- Coefficient of thermal expansion of glass
- Coefficient of thermal expansion of silicon
- Shear strength of joint material
- Joint thickness
- Joint width
- Number of cells in a string
- Cell width
- DOW CORNING

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Implications for joint material

\[ G(-\Delta T) \left\{ L_0 \alpha_{\text{glass}} - \alpha_{\text{Si}} [n l_0 - (n - 1) w_0] \right\} < 1 \]

\[ \frac{G}{\tau_{\text{sh. str.}}} \cdot t(n - 1) \]

Ratio \( \frac{G}{\tau_{\text{sh. str.}}} \) should be as low as possible

Additionally, adhesion between joint material and metallization material has to be excellent (only cohesive failure)
Conductivity versus strength challenge for ECA’s

- Percolation threshold

Resistivity

Filler content

- Filler content always high

High filler content
No adhesion at particle/substrate interface
Filler provides less cohesion than polymer matrix

• Strength is substantially lower than adhesive without filler
• Optimization needed for best resistivity with sufficient adhesion/strength
Optimization of material solutions

- Low G and high shear strength are needed

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<tr>
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<th>Eutectic tin lead solder</th>
<th>Epoxy ECA</th>
<th>Silicone ECA</th>
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<tr>
<td>G (MPa)</td>
<td>12000</td>
<td>200 - 2000</td>
<td>10 - 100</td>
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<tr>
<td>$\tau_{sh. , str.}$ (MPa)</td>
<td>40</td>
<td>5 - 10</td>
<td>0.3 - 1</td>
</tr>
<tr>
<td>$G/\tau_{sh. , str.}$</td>
<td>300</td>
<td>20 - 400</td>
<td>10 - 300</td>
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<tr>
<td>Resistivity (ohm cm)</td>
<td>$0.15 \times 10^{-4}$</td>
<td>$1 - 25 \times 10^{-4}$</td>
<td>$2 - 30 \times 10^{-4}$</td>
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- Two adhesives solution

![Diagram of adhesives and busbar](image.png)
Conclusion

- Shingled cells interconnection: emerging interconnection technology

- Soldering: not suitable

- Joint material needs low $\frac{G}{\tau_{sh.str.}}$ ratio

- Silicone ECA: much lower G throughout temperature range

- Using a two adhesives approach could help solve assembly challenges
Thank you!

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