Failure Analysis of Electrically Conductive Adhesive Interconnects by X-Ray Tomography

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Electrically conductive adhesives (ECAs) solar applications

- ECAs present an exciting opportunity for the solar industry
- Commercial modules are relatively new and their failure mechanisms are widely not understood
ECAs are adhesive materials such as epoxy or silicone filled with conductive metal particles like silver and/or copper.

<table>
<thead>
<tr>
<th>Paste</th>
<th>Filler</th>
<th>Metal %</th>
<th>$\rho$ (m$\Omega$cm</th>
<th>$G @ 25^\circ$C (MPa)</th>
<th>$T_a$(°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPOXY 1</td>
<td>Ag flakes</td>
<td>25-50</td>
<td>100</td>
<td></td>
<td>50-60</td>
</tr>
<tr>
<td>EPOXY 2</td>
<td>Ag &amp; Cu flakes</td>
<td>60-100</td>
<td>0.4</td>
<td>1720</td>
<td>Onset: 55-90 Tandelta: 16</td>
</tr>
<tr>
<td>EPOXY 3</td>
<td>Ag &amp; Cu flakes</td>
<td>70-100</td>
<td>0.5</td>
<td>160</td>
<td>Tandelta: -10</td>
</tr>
<tr>
<td>EPOXY 4</td>
<td>Ag &amp; Cu flakes</td>
<td>70-90</td>
<td>0.32</td>
<td>212</td>
<td>Onset: -10 Tandelta: 16</td>
</tr>
<tr>
<td>EPOXY 5</td>
<td>Ag &amp; Cu flakes</td>
<td>~ 80</td>
<td>0.3</td>
<td>80</td>
<td>Onset: -30 Tandelta: -15</td>
</tr>
<tr>
<td>EPOXY 6</td>
<td>Ag &amp; Cu flakes</td>
<td>~ 80</td>
<td>0.2</td>
<td>170</td>
<td>Onset: -20 Tandelta: 0</td>
</tr>
<tr>
<td>SILICONE</td>
<td>Ag &amp; Cu particles</td>
<td>83-88</td>
<td>0.18</td>
<td>Low</td>
<td></td>
</tr>
</tbody>
</table>
Project motivation

ECA interconnections throughout damp heat\(^1\)

- Minimal literature about the mode of ECA failure

Solder damage modelled in different climates\(^1\)

- Collaborating with Nick Bosco at NREL to produce a similar model but for ECA interconnections

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Mini-module fabrication and failure monitoring

Accelerated ageing testing:
- Thermocycling (TC) (-40°C to 85°C)
- Damp heat (testing pending)

Failure monitoring:
- I-V and Suns $V_{oc}$
- Electroluminescence
- Series resistance mapping

Failed sample analysis:
- X-ray transmission
- X-ray tomography
- Cross-sectional SEM
- Elemental mapping by EDXS

Stencil print ECA onto Cell 1 busbar

Introduction to x-ray tomography

- Based on x-ray transmission imaging
- Program processes transmission images into a 3D rendering of sample
- Up to ~1μm/pixel resolution
- Differentiates materials by densities

Example of a 3D rendering from x-ray tomography

Cone Beam Computed Tomography System Diagram

Series resistance mapping throughout thermocycling

<table>
<thead>
<tr>
<th></th>
<th>0 TC</th>
<th>50 TC</th>
<th>100 TC</th>
<th>300 TC</th>
<th>500 TC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rs (Ω cm²)</td>
<td>0.55</td>
<td>0.61</td>
<td>0.63</td>
<td>0.66</td>
<td>0.71</td>
</tr>
</tbody>
</table>
X-ray transmission imaging after 500 TC

X-Ray transmission image of busbar

Ag fingers

ECA
Comparing X-ray transmission with SEM cross section
X-ray transmission images from different samples with same processing
Processing analysis by transmission imaging

Lamination Curing

- Blade coating produces wide variability in the distribution of metal particles in ECA layer
- Lamination alone has no notable affect on ECA metal distribution

Hot Plate Cure, pre-lamination

Hot Plate Cure, post-lamination
ECA dispensing tool

Before lamination:

After lamination:
Tomography scan

Transmission image of scan area

Top to Bottom Cell (z axis)

Through Busbar (y axis)
Tomography still images

Transmission

Side Profile

Cross Section

Top-Down

300 µm

300 µm

300 µm

300 µm

300 µm

300 µm

300 µm

300 µm
Tomography scan

Transmission

Top to bottom cell (z axis)

Through busbar (y axis)
Features shown through x-ray tomography

- Voids (~10-130μm)
- Cracks
- Delamination from busbar
- Larger metal particles
- Viable conduction pathways
- Voids in screen printed busbars

Interface of ECA and busbar

[Images showing features like cracks, delamination, larger metal particles, and voids in busbar]
## Future plan

<table>
<thead>
<tr>
<th>Step</th>
<th>Initial characterization</th>
<th>Re-characterize through TC/DH</th>
<th>Cut sample for tomography and cross-sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabricate mini-module</td>
<td>0 TC</td>
<td>100, 200…TC</td>
<td></td>
</tr>
<tr>
<td>New module design using the ECA dispensing tool</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial characterization</td>
<td></td>
<td></td>
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<tr>
<td>Re-characterize through TC/DH</td>
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<tr>
<td>Cut sample for tomography and cross-sections</td>
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</table>

*We can begin here for failed industrial samples*
**X-ray transmission and tomography summary**

**X-Ray Transmission**

- Non-destructive
  - Can be added to characterization throughout TC/DH

- 2D imaging of metal distribution throughout ECA
  - Misalignment
  - Voids
  - Relative information about thickness

- Informs where to run tomography scan

**X-Ray Tomography**

- 3D imaging of metal distribution in ECA
  - 3D understanding of conduction pathways
  - 3D voids
  - Cracks
  - Delamination
  - Larger metal particles
  - Up to 1μm/pixel resolution

- Informs where to make cross section for SEM and EDXS
Thank you for your attention!

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Acknowledgements