Stress Induced Degradation Modes in CIGSS Minimodules

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Experimental Objectives

- Compare the performance of modules exposed to high temperature and humidity.
- Determine the effects of different encapsulants on long term stability of CIGSS modules.
- Analyze failure modes to determine areas in need of improvement.
Experimental Setup

- Systematically changed:
  - (1) Encapsulant (EVA or GE RTV615 silicone)
  - (2) Front-sheet (Glass or Tefzel)

- Samples exposed to:
  - (1) 85°C/85% RH in air.
  - (2) 85°C/0% RH in air. (Dew point ~ -40°C)

- Used 4 or 5 replicates. $4 \times 2^3 + 2 = 34$ samples.

- Initial average cell parameters:
  - $V_{oc} = 0.538$ V
  - $J_{sc} = 32.8$ mA/cm²
  - FF = 65.7%
  - $\eta = 11.59\%$
Stress at 85°C and 85% RH Causes Rapid Degradation

Silicone with Tefzel Front-Sheet  

EVA with Glass Front-Sheet

Glass Slows down the degradation but does not prevent it.
Infrared Images Shows a Striped Pattern

Silicone encapsulant with a Tefzel Front-Sheet. Module #32

457 h of 85 ºC and 85% RH

-0.24 mA, -9.6 V
Reverse Bias
No Signs of Shunts

+81 mA, 9.6 V
Forward Bias

Weak Diodes
(i.e. small area with low $V_{oc}$)
IR Heat Pattern Indicates High Resistance ZnO

IR image of module under forward bias of 9.6V and 81 mA.

Heating not symmetric around the scribe and therefore is not due to resistance in interconnection scribes.

Schematic representation of CIGSS cell interconnection scheme

ZnO
CIGSS
Mo
Glass
P1  P2  P3
P1  P2  P3
Heating Caused Principally by Recombination Current

\[ j = j_o \left[ \exp\left( \frac{qV}{nKT} \right) - 1 \right] \]

ZnO
CIGSS
Mo
Glass
85°C and 0% RH Exposure Causes $V_{oc}$ and FF Losses

Silicone

Shell Solar CIGSS #13
Laminated with EVA
Glass Frontsheet
Stressed at 85°C/0% RH
0 h
1 h
103 h
199 h
457 h
935 h
1574 h
2287 h
3607 h
4663 h
6463 h
8767 h

EVA

Shell Solar CIGSS #29
Laminated with GE RTV615
Dow Corning 1200 Primer
Tefzel Frontsheet
Stressed at 85°C/0% RH
0 h
1 h
103 h
199 h
457 h
935 h
1574 h
2287 h
3607 h
4663 h
6463 h
8767 h

Silicone encapsulated cells performed better. They had better fill factors and less roll over.
An Analysis of Variance Indicates Statistical Significance

<table>
<thead>
<tr>
<th>Treatment</th>
<th>$\Delta V_{oc}$ F Ratio</th>
<th>$\Delta V_{oc}$ Probability</th>
<th>$\Delta J_{sc}$ F Ratio</th>
<th>$\Delta J_{sc}$ Probability</th>
<th>$\Delta FF$ F Ratio</th>
<th>$\Delta FF$ Probability</th>
<th>$\Delta Efficiency$ F Ratio</th>
<th>$\Delta Efficiency$ Probability</th>
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</thead>
<tbody>
<tr>
<td>Front-sheet</td>
<td>0.005</td>
<td>0.94</td>
<td>0.40</td>
<td>0.54</td>
<td>0.015</td>
<td>0.91</td>
<td>0.16</td>
<td>0.70</td>
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<tr>
<td>Encapsulant</td>
<td>0.55</td>
<td>0.47</td>
<td>0.080</td>
<td>0.78</td>
<td>13.5</td>
<td>0.0036</td>
<td>6.66</td>
<td>0.026</td>
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<tr>
<td>Encapsulant*Front-Sheet</td>
<td>0.14</td>
<td>0.72</td>
<td>1.15</td>
<td>0.3</td>
<td>0.52</td>
<td>0.49</td>
<td>0.36</td>
<td>0.56</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment</th>
<th>$\Delta R_{sh, light}$ F Ratio</th>
<th>$\Delta R_{sh, light}$ Probability</th>
<th>$\Delta R_{S, light}$ F Ratio</th>
<th>$\Delta R_{S, light}$ Probability</th>
<th>$\Delta R_{sh, dark}$ F Ratio</th>
<th>$\Delta R_{sh, dark}$ Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front-sheet</td>
<td>1.6</td>
<td>0.23</td>
<td>0.0012</td>
<td>0.97</td>
<td>0.27</td>
<td>0.62</td>
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<tr>
<td>Encapsulant</td>
<td>0.19</td>
<td>0.67</td>
<td>8.3</td>
<td>0.0149</td>
<td>3.16</td>
<td>0.10</td>
</tr>
<tr>
<td>Encapsulant*Front-Sheet</td>
<td>0.0021</td>
<td>0.96</td>
<td>0.77</td>
<td>0.40</td>
<td>0.047</td>
<td>0.83</td>
</tr>
</tbody>
</table>

Resistances determined from inverse slope.

Two factor ANOVA for samples exposed to 8767 h of 85°C and 0% RH.

“F ratio” is the ratio of the uncertainty between treatments to the sample set uncertainty.

“Probability” is the chance of getting this F ratio if the two treatments were actually equivalent.

“Encapsulant*Front-sheet” indicates the probability that interactions between treatments significantly affect the results.
Silicone Encapsulated Cell Have Lower FF and “R_s” Losses

8767 hours of 85ºC and 0% RH

Resistances were inferred from the inverse slope. The horizontal lines for each data set correspond to the 95% confidence interval for the magnitude of the changes. The large horizontal line spanning the plots is the grand mean for the data set.
At 8767 h 85°C and 0% RH
ZnO Resistance Has Increased

Forward Bias Module #15
9.5 V, 31 mA, 15 s
8767 h 85°C and 0% RH
EVA/Tefzel
IR Images Distinguish Weak Diodes from Shunts

Silicone/Tefzel after 2290 h 85°C and 0% RH. #29

5 s Reverse Bias
9.3 V 0.53 mA

5 s forward Bias
9.3 V 153 mA

Flashlight Illumination

IR images are made by subtracting image values before and after application of voltage.
Many Weak Diodes Are Located on the P1 scribe

Flashlight Illumination

The flashlight illuminated the side of the cell just outside the image to ensure that we were not just seeing a reflection.

Silicone/Tefzel after 2290 h 85ºC and 0% RH. #29
Weak Diodes Principally Located at P1 Scribes or Cell Edge

Silicone/Tefzel after 2290 h
85ºC and 0% RH.

9.3V and 153 mA
Applied for 20 s

Module #29
The Number of Weak Diodes Barely Changed

Module #30, Silicone/Tefzel at 85°C/0% RH

Reverse Bias

Forward Bias

Shunts

2 mA, -9.6V
20s
2290 h Exposure

Shunts and Weak Diodes

2.3 mA, -9.5V
20s
8770 h Exposure

90 mA, 9.6 V
20s
2290 h Exposure

50 mA, 9.5 V
20s
8770 h Exposure
Diodes are Weaker but Shunting is Unchanged

8770 h exposure to 85°C and 0% RH

$V_{oc}$

$R_{shunt, light}$

Similar change in $V_{oc}$ across all sample sets. No statistically significant change in Shunts.
Conclusions

- Exposure to 85°C and 85% RH for 457 h or 935 h:
  - Large increases in ZnO resistance.
  - Some $V_{oc}$ losses.

- Exposure to 85°C and 0% RH for 8767 h:
  - Small increases in ZnO resistance.
  - Some $V_{oc}$ losses.
  - No shunting change.
  - Silicone encapsulated cells performed better than EVA.
  - EVA produced greater losses in FF and series resistance.
Acknowledgements

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