Accelerating Fatigue Testing for Cu Ribbon Interconnects

Nick Bosco, Tim Silverman, John Wohlgemuth and Sarah Kurtz
National Renewable Energy Laboratory

Masanao Inoue and Keiichiro Sakurai
National Institute of Advanced Industrial Science and Technology

Tsuyoshi Shioda and Hiroyumi Zenkoh
Mitsui Chemical

Masanori Miyashita
Toray

Tanahashi Tadanori and Satoshi Suzuki
Espec
Motivation

Thermal cycling a module takes a long time
2012 NREL PVMRWS: fatigue experiments
2012 NREL PVMRWS: fatigue experiments

\[ \frac{\Delta \varepsilon_{pl}}{2} = \varepsilon'_f \left(2N_f\right)^{-c} \]

\[ \frac{\Delta \varepsilon_{el}}{2} = \frac{\sigma'_f}{E} \left(2N_f\right)^{-b} \]
2012 NREL PVMRWS: fatigue experiments

- Strain amplitude %
- Cycles to failure

- 1.5mm w/o spacer
- 1.5mm w/spacer
- 0mm off-set

- Diagram with various symbols representing different conditions and cycles to failure.
Dynamic Mechanical Loading

- Can we mechanically load a module to induce ribbon strain?
- If so, how is the ribbon strain distributed across the module?
- Can DML cause ribbon failure similar to thermal cycling?
- If so, what is the acceleration factor between DML and thermal cycling?
Dynamic Mechanical Loading

Modules fabricated by AIST and collaborators

DML set up fabricated and employed by NREL

100 cm

120 cm

glass front
frame
stiff back plane

control
strain measurements

- Measuring cell-to-cell spacing

- Calculating ribbon strain

\[ \varepsilon = \frac{(du_L - du_i)}{du_i} \]
Increasing module temperature allows more strain for similar loads.
strain measurements

![Graph showing strain measurements at 25 °C and 37 °C with a probability range of +/- 3000 Pa.](image)

The graph illustrates the relationship between strain amplitude and probability, with distinct lines for 25 °C and 37 °C conditions.
strain with cycling

Effects of the encapsulant’s viscoelasticity are not observed
test plan

<table>
<thead>
<tr>
<th>dynamic mechanical loading</th>
<th>thermal cycling</th>
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<tbody>
<tr>
<td>high w/bias</td>
<td>high</td>
</tr>
<tr>
<td>low w/bias</td>
<td>high</td>
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</tbody>
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<table>
<thead>
<tr>
<th>2mm offset</th>
<th>2</th>
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<tbody>
<tr>
<td>10mm offset</td>
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- **initial measurements**
- **characterize**
  - EL
  - IR
  - LIV
  - DIV
- **End of life?**
- **test**
- **measure**
  - DPA
differential conductance \((dG)\)

- Forward bias with short circuit current
- Apply a small sinusoidal voltage superimposed on the DC bias
- Monitor the AC voltage across and AC current through the module
$dG$ declines with increasing module temperature as it heats under fwd bias.

$dG$ becomes periodic with cycling (mechanical connections).

$dG$’s low side drops with ribbon failure as negative pressure causes positive strain pulling the ribbons open.

Steps are seen with every subsequent failure.

Following cycling, $dG$ becomes some intermediate value.
DML +/-3000 Pa Isc

Initial as-received EL image

EL image following 1000 DML cycles. Roughly 7 ribbon failures obvious

Under positive pressure, failed ribbons close. Under negative pressure, the module becomes open suggesting at least one more failure.
Module shows higher series resistance under zero pressure, and is open under negative pressure.

Consistent with monitoring and EL images.
DML +/-3000 Pa Isc

\[dG\] captures ribbon failures through first 1000 cycles

Shortly after 1000 cycles, module becomes open. Those cells are bypassed to continue experiment

M1212_0003
DML +/-3000 Pa no bias

10 mm offset

1000 cycles
2000 DML cycles
3000 DML cycles

3 ribbon failures obvious
3 ribbon failures obvious
6 ribbon failures obvious

M1212_0012
Half of the module's ribbons should fail within 6000 cycles
Dynamic Mechanical Loading

- Module ribbon strain with DML has been characterized
- Fatigue failures are realized first for those with the highest strain amplitude
- $dG$ monitoring captures failures
- Stay tuned for:
  - Acceleration factor with TC
  - FEM for strain amplitudes with module size