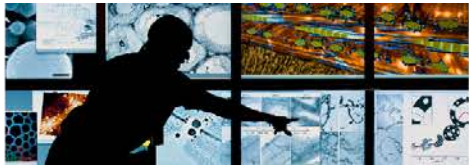
2013 Photovoltaic Module Reliability Workshop
February 26-27, 2013
NREL/PR-5200-58369

Accelerating Fatigue Testing for Cu Ribbon Interconnects



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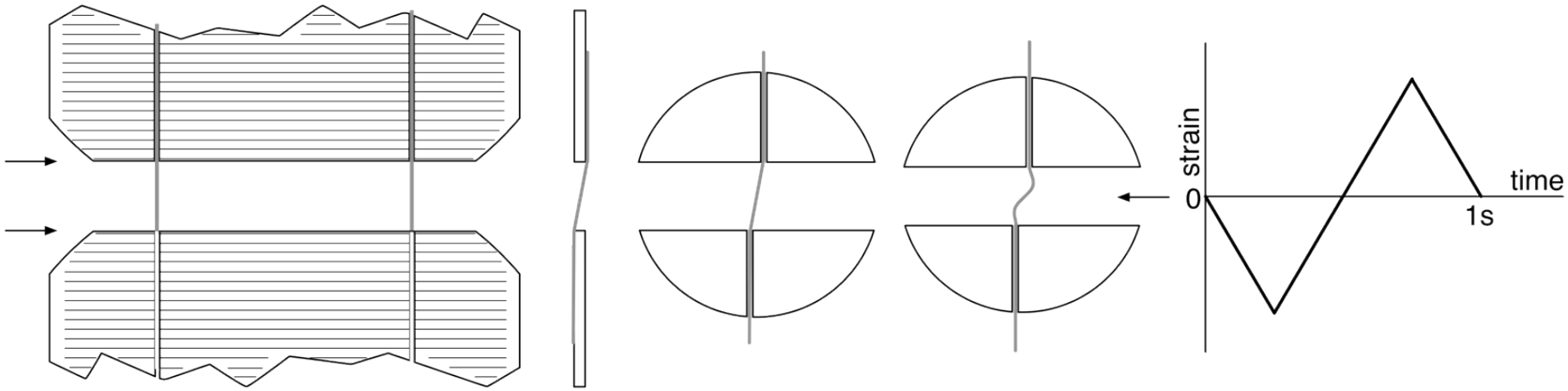
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

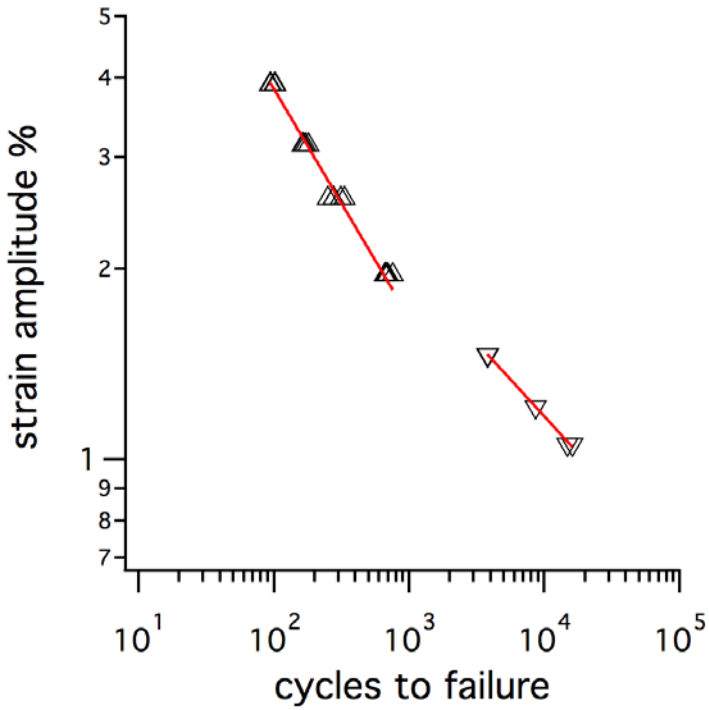
Motivation

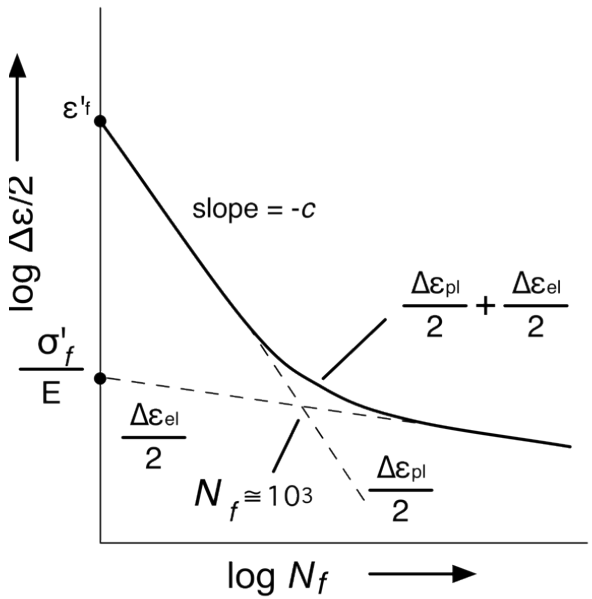
Thermal cycling a module take a long time

2012 NREL PVMRWS: fatigue experiments



2012 NREL PVMRWS: fatigue experiments

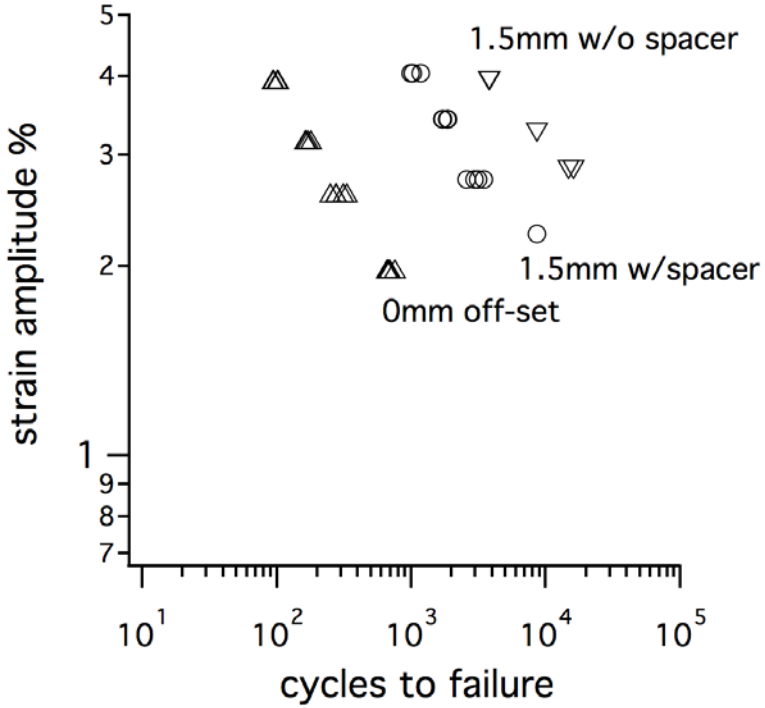


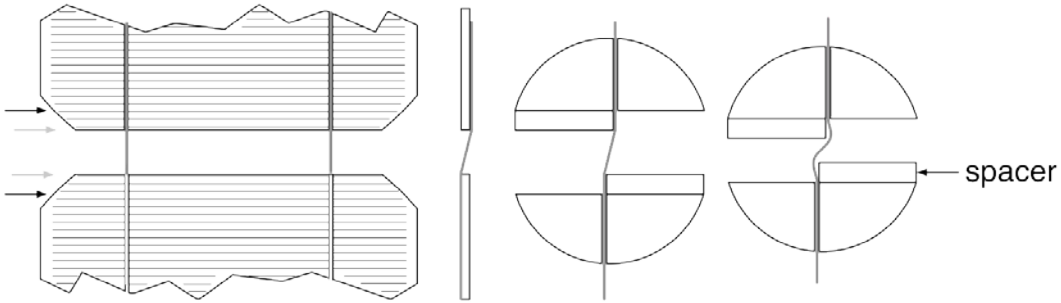


$$\frac{\Delta\varepsilon_{pl}}{2} = \varepsilon'_f \left(2N_f\right)^{-c}$$

$$\frac{\Delta\varepsilon_{el}}{2} = \frac{\sigma'_f}{E}\left(2N_f\right)^{-b}$$

2012 NREL PVMRWS: fatigue experiments

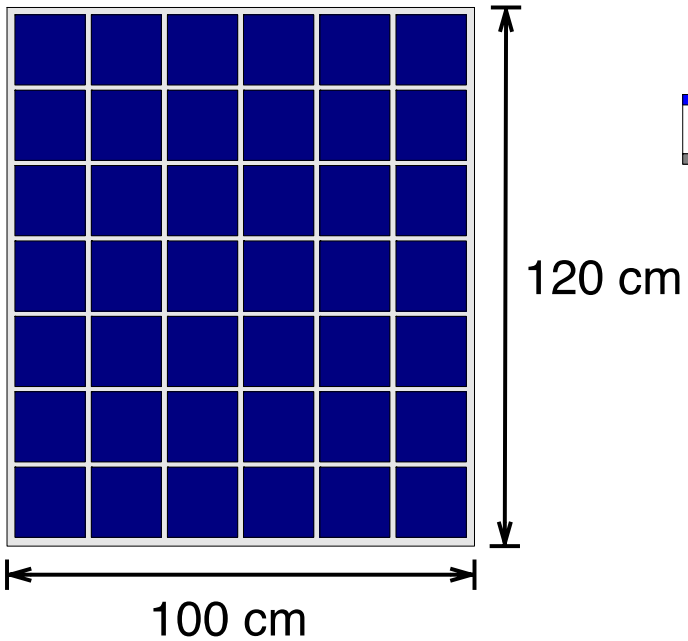




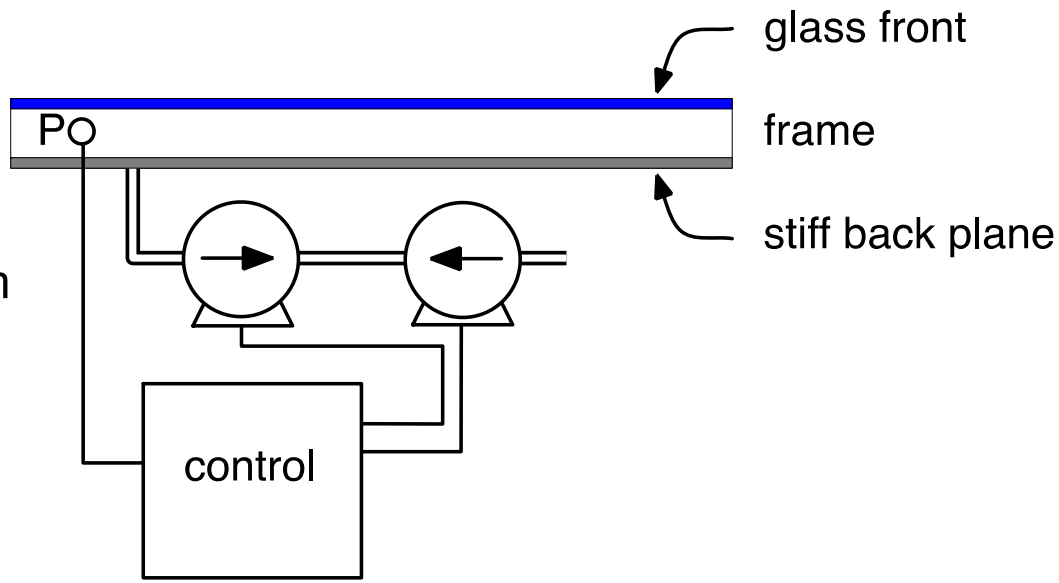
Dynamic Mechanical Loading

- 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



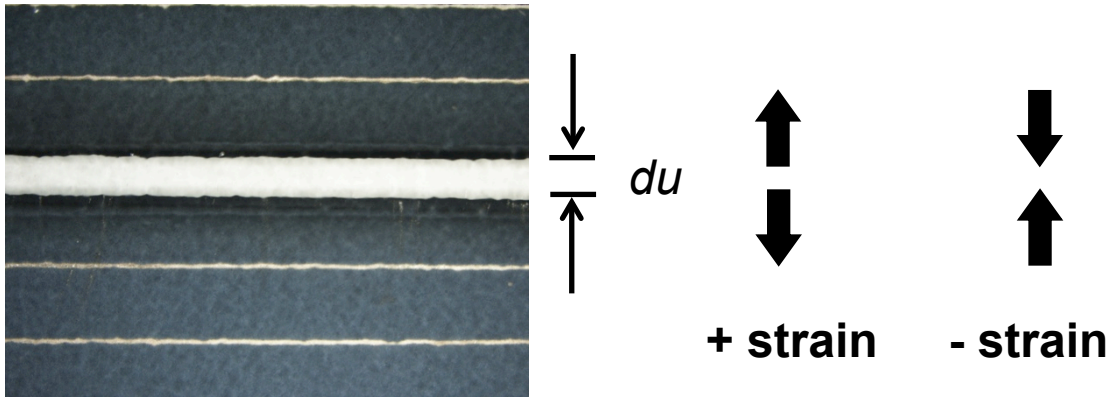
Modules fabricated by AIST and collaborators



DML set up fabricated and employed by NREL

strain measurements

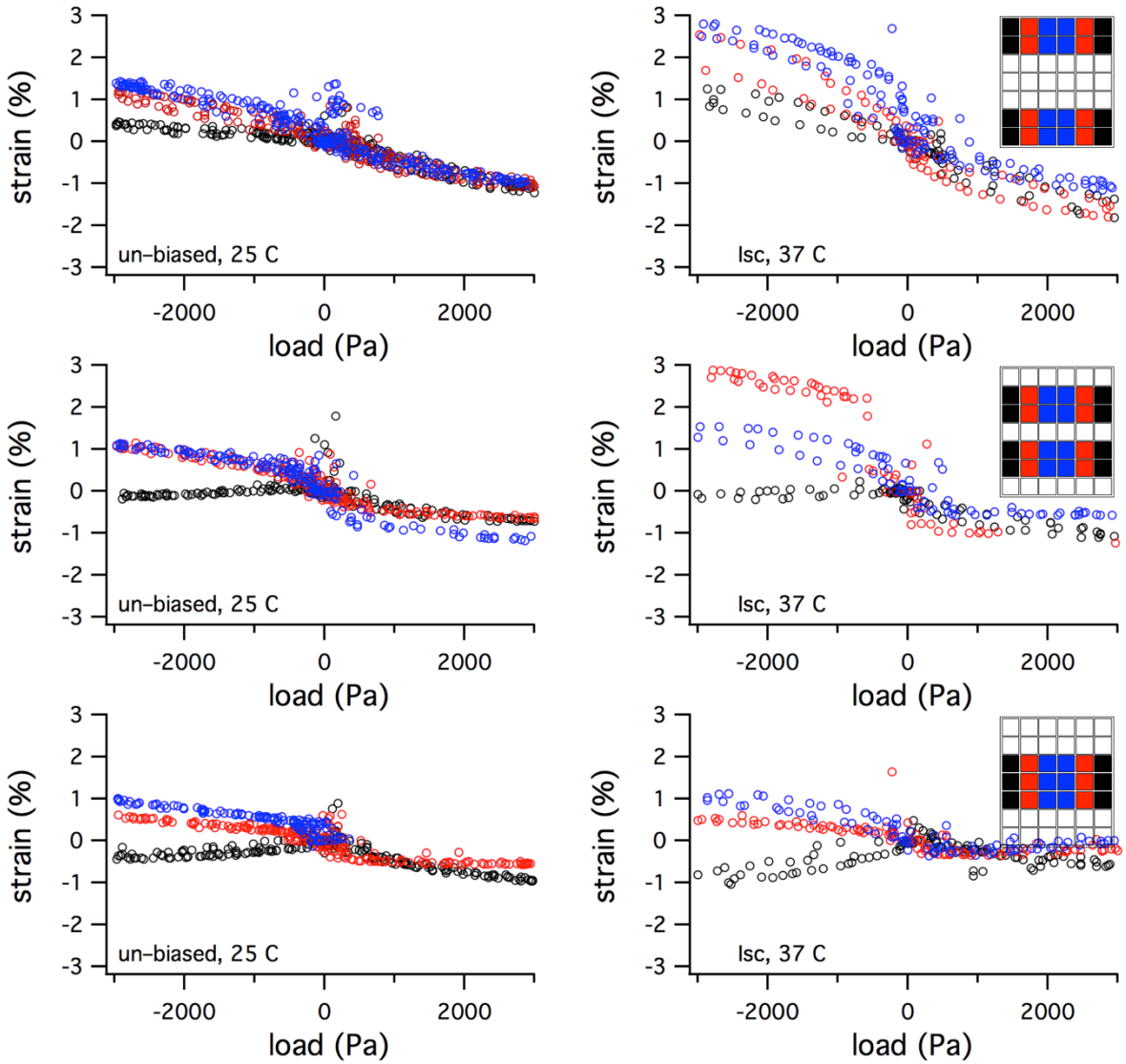
- **Measuring cell-to-cell spacing**



- **Calculating ribbon strain**

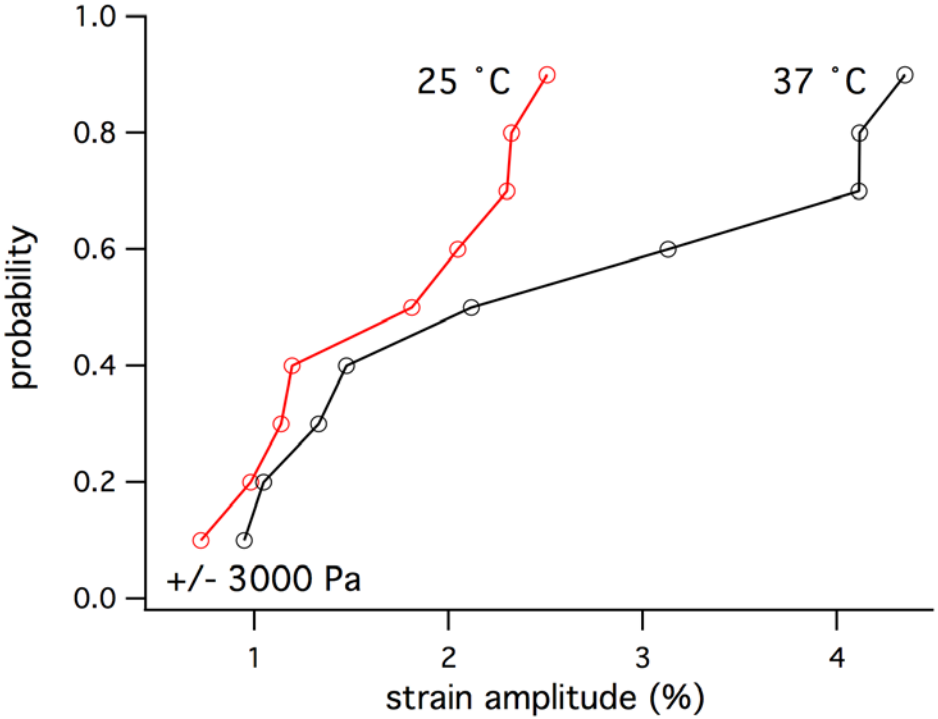
$$\varepsilon = \frac{\left(du_L - du_i\right)}{du_i}$$

strain measurements

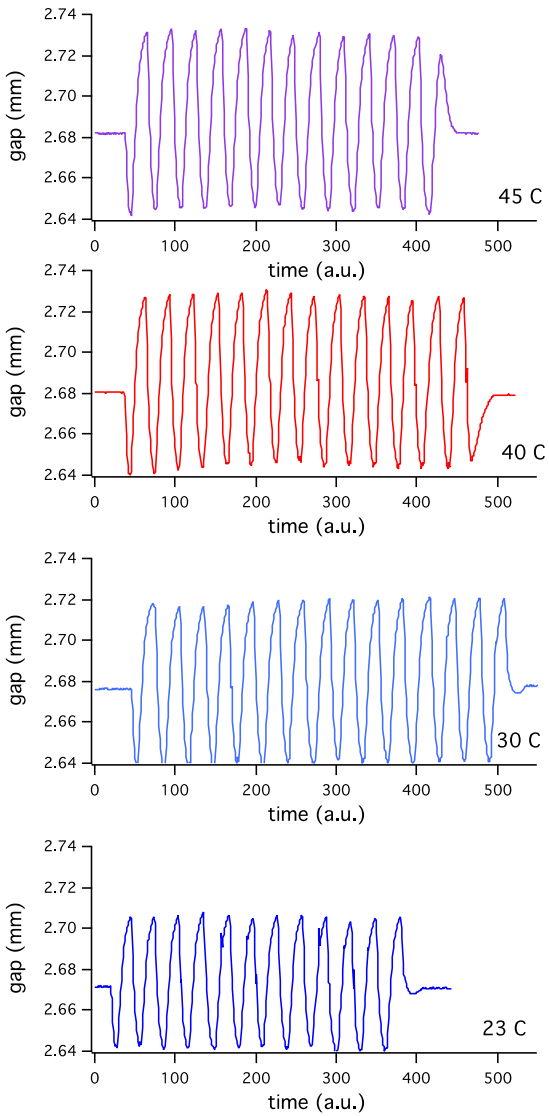


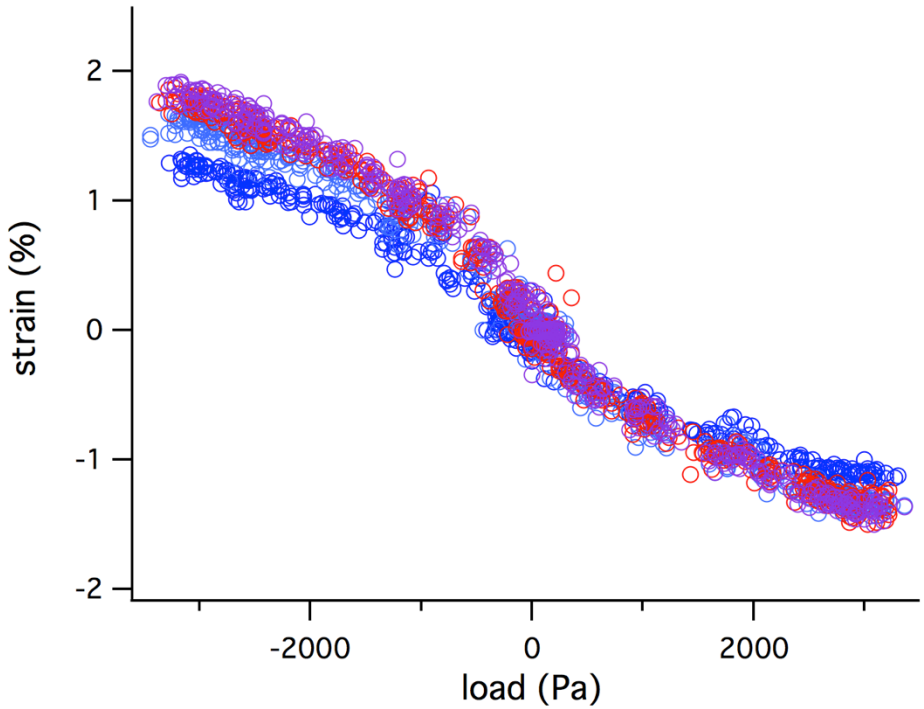
Increasing module temperature allows more strain for similar loads

strain measurements



strain with cycling

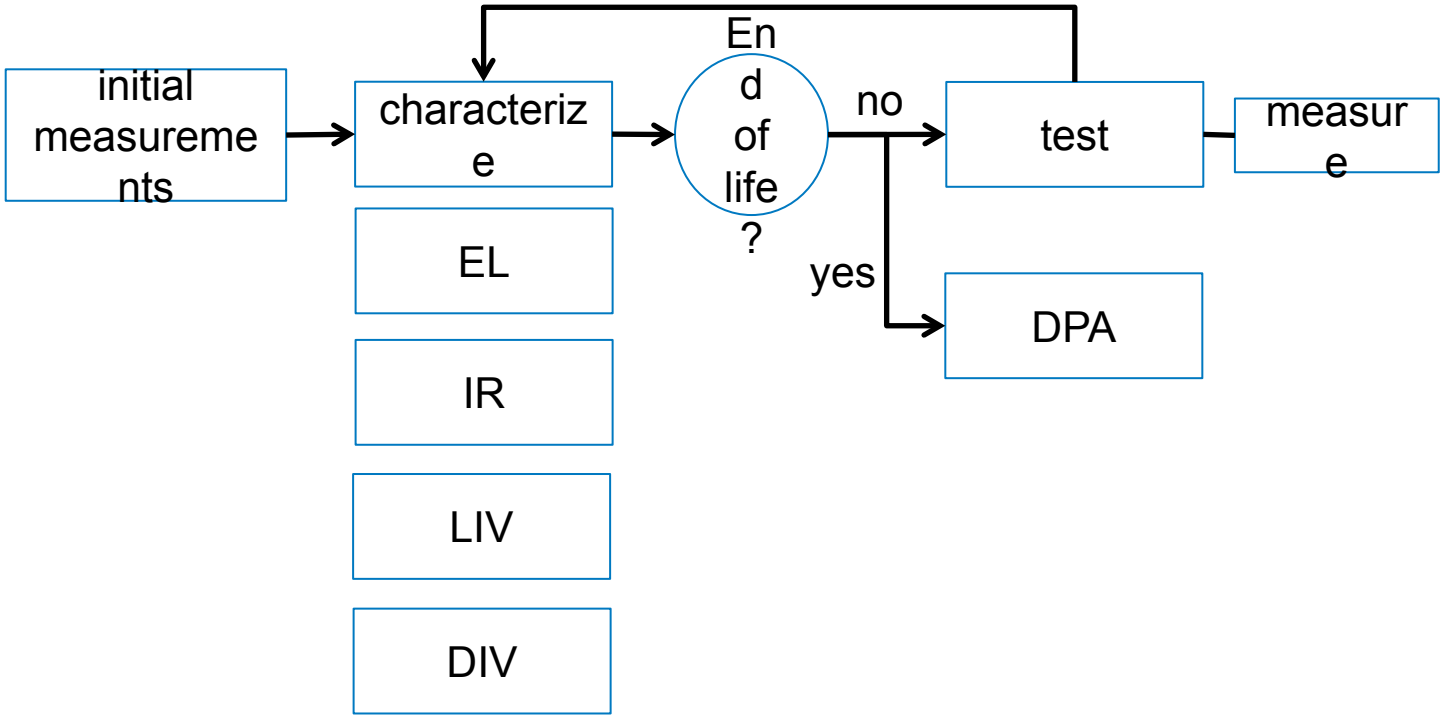




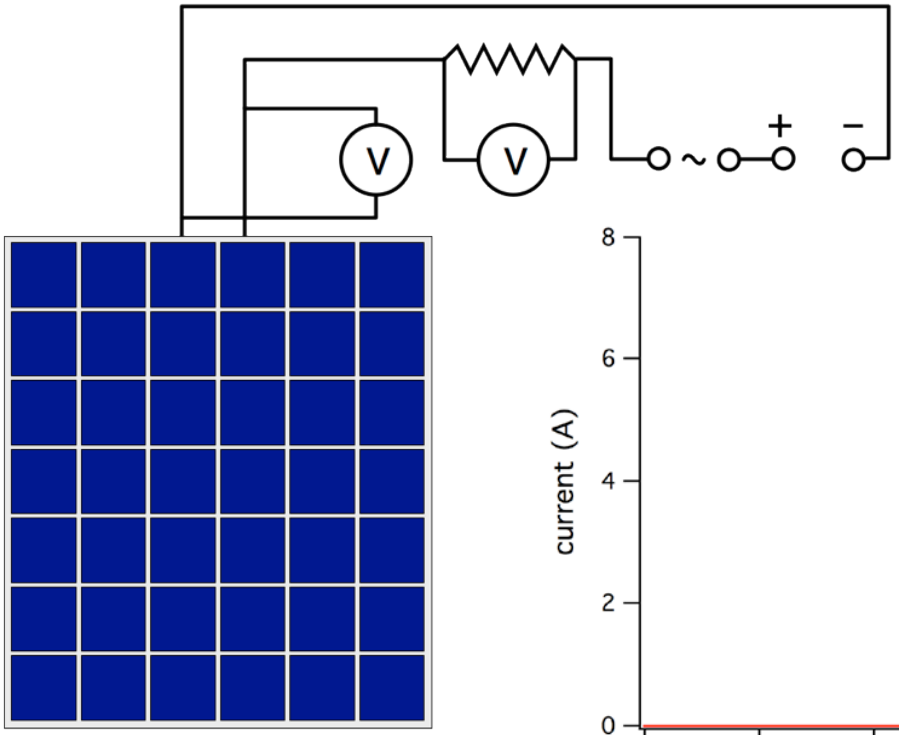
Effects of the encapsulant's viscoelasticity are not observed

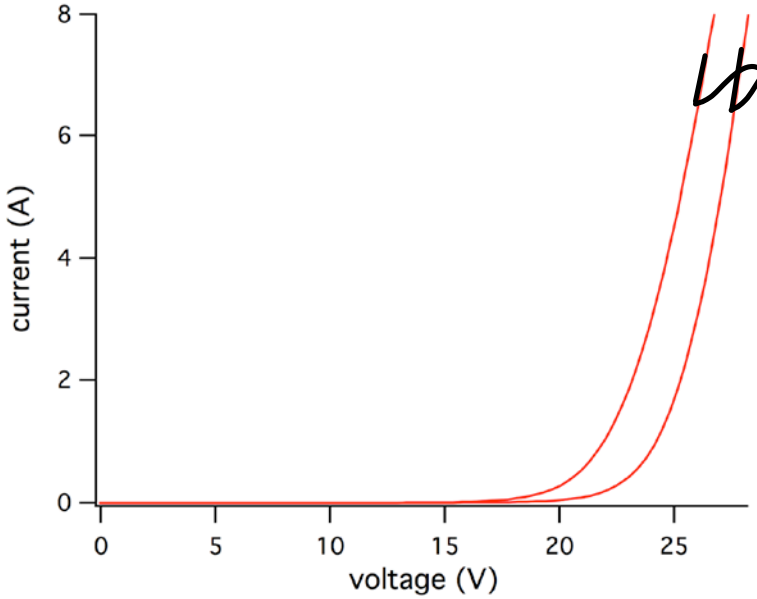
test plan

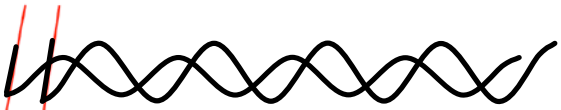
	dynamic mechanical loading			thermal cycling
	high w/bias	low w/bias	high	
2mm offset	2	2	2	2
10mm offset	2	2	2	2



differential conductance (*dG*)

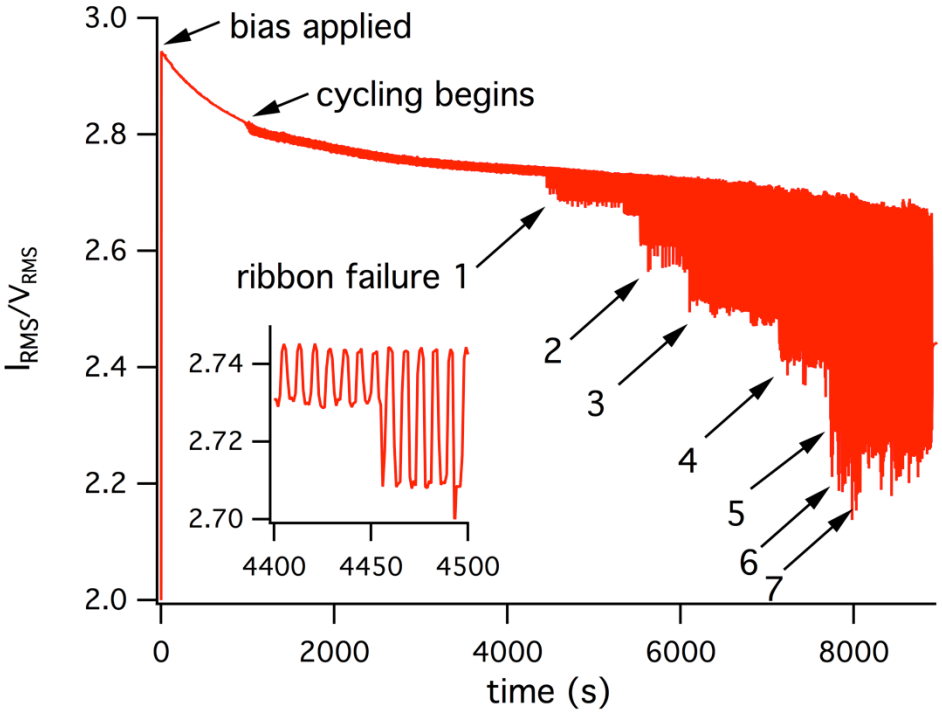






- Forward bias with short circuit current
- Apply a small sinusoidal voltage superimposed on the DC bias
- Monitor the AC voltage across and AC current through the module

DML +/-3000 Pa Isc



dG declines with increasing module temperature as it heats under fwd bias.

dG becomes periodic with cycling (mechanical connections).

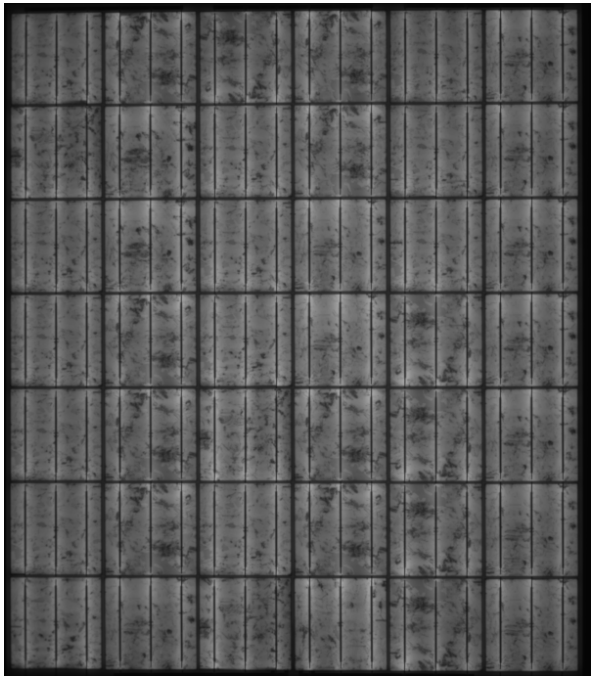
dG's low side drops with ribbon failure as negative pressure causes positive strain pulling the ribbons open.

Steps are seen with every subsequent failure.

Following cycling, *dG* becomes some intermediate value.

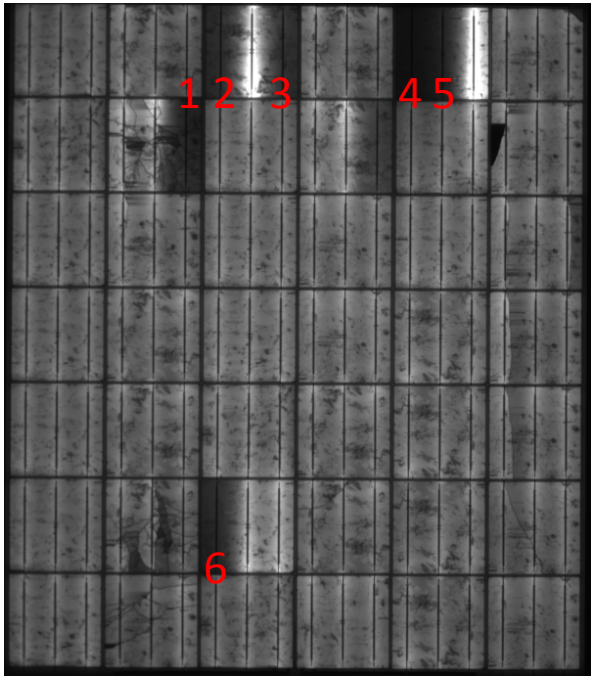
M1212_0003

DML +/-3000 Pa Isc



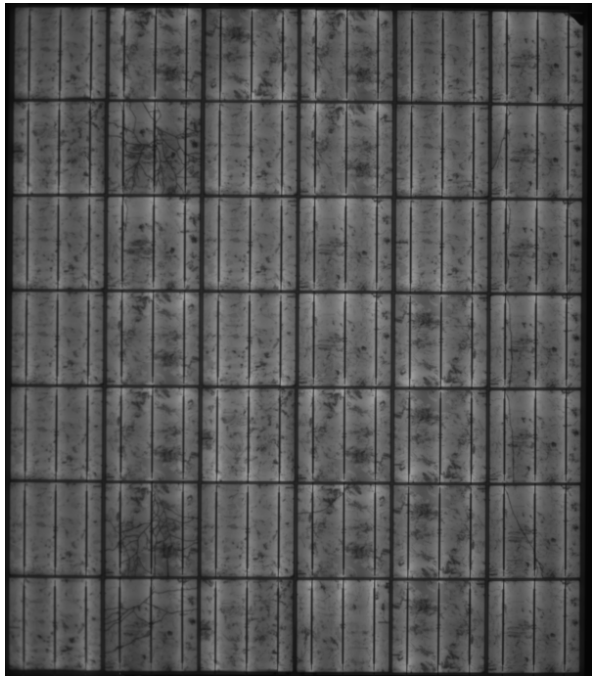
Initial as-received EL image

0 Pa



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

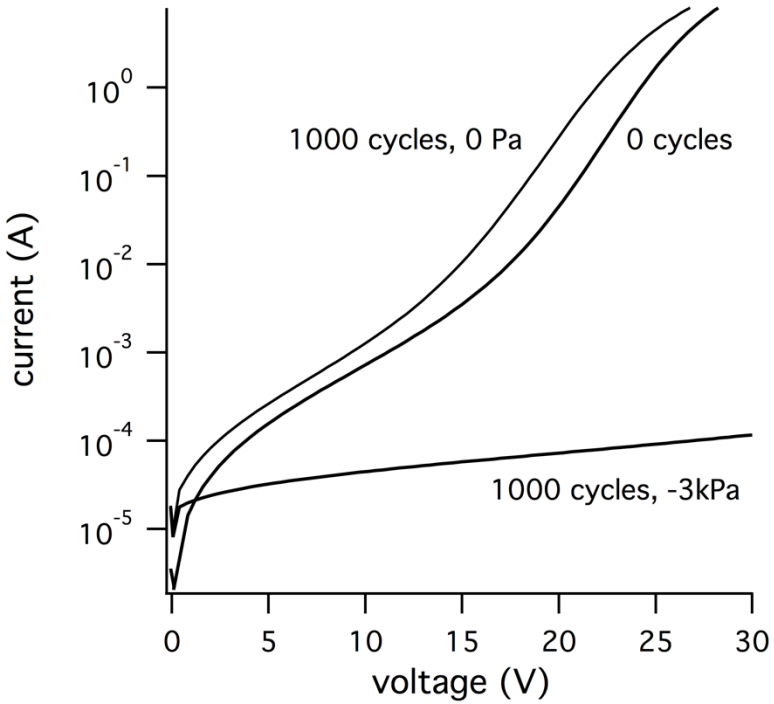
+ Pa



Under positive pressure, failed ribbons close. Under negative pressure, the module becomes open suggesting at least one more failure.

M1212_0003

DML +/-3000 Pa Isc

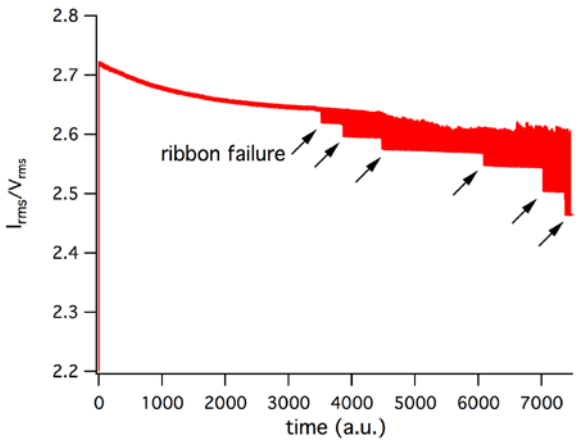


Module shows higher series resistance under zero pressure, and is open under negative pressure.

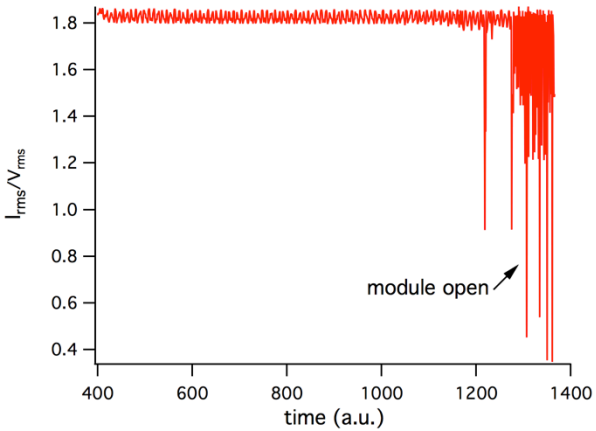
Consistent with monitoring and EL images.

M1212_0003

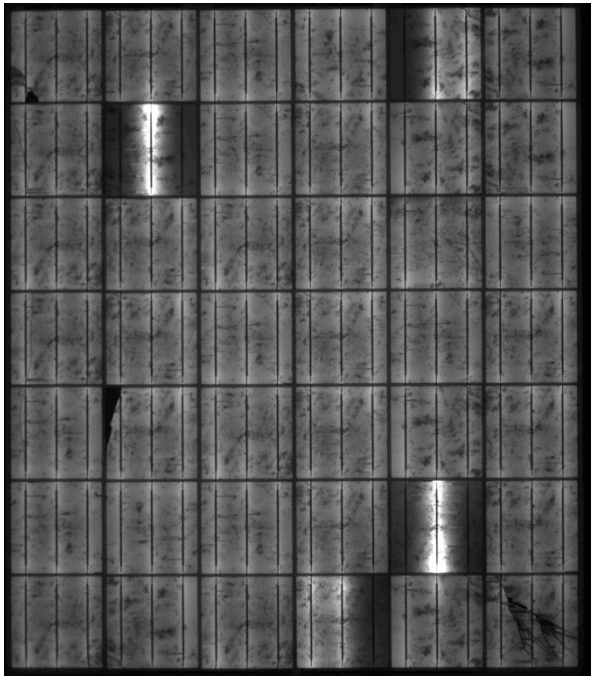
DML +/-3000 Pa Isc

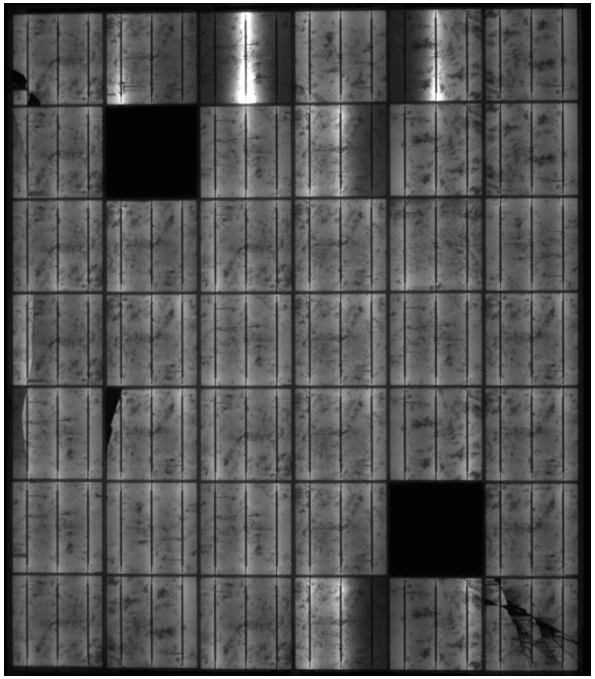


dG captures ribbon failures through first 1000 cycles



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

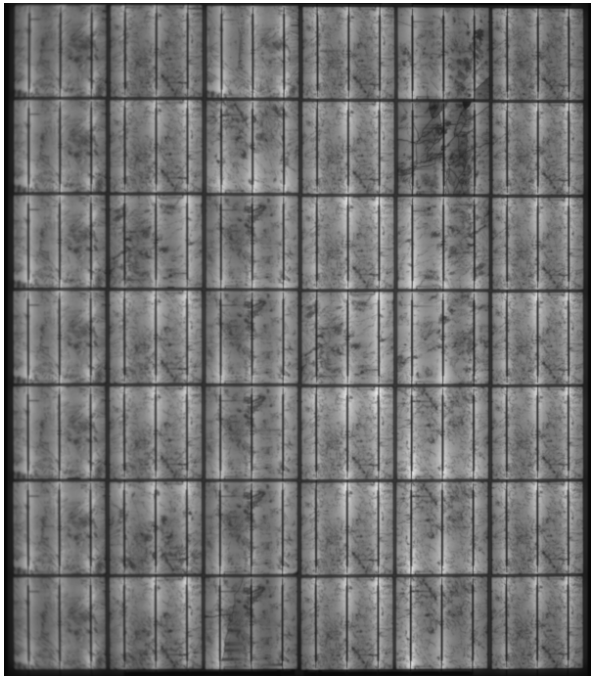




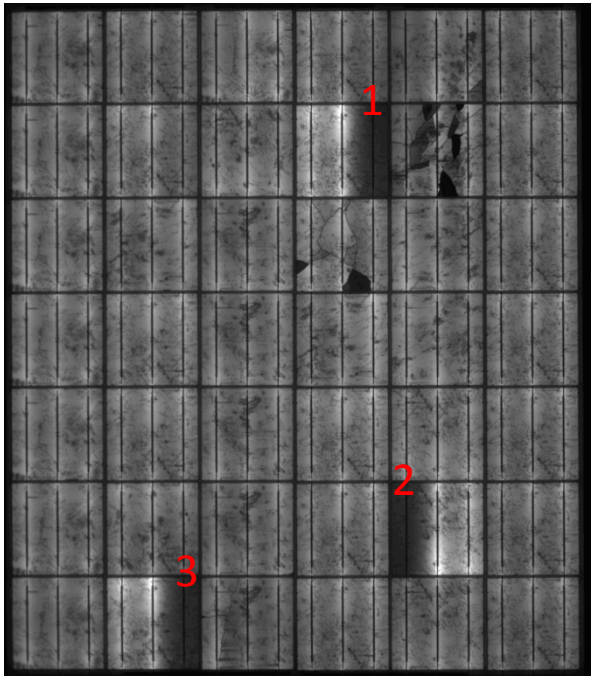
M1212_0003

DML +/-3000 Pa no bias

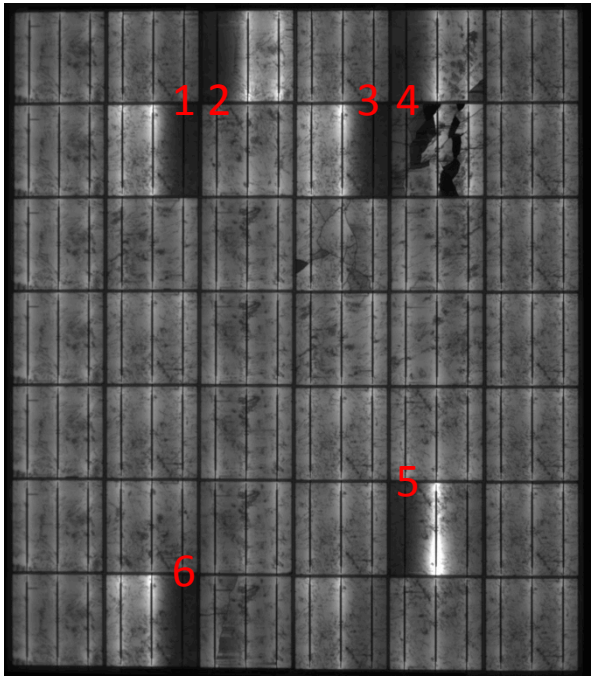
10 mm offset



1000 cycles



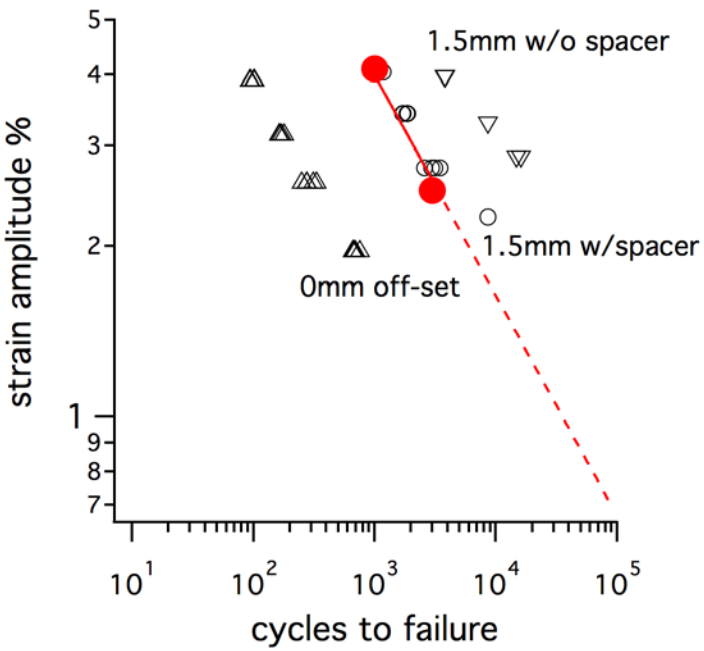
2000 DML cycles
3 ribbon failures obvious

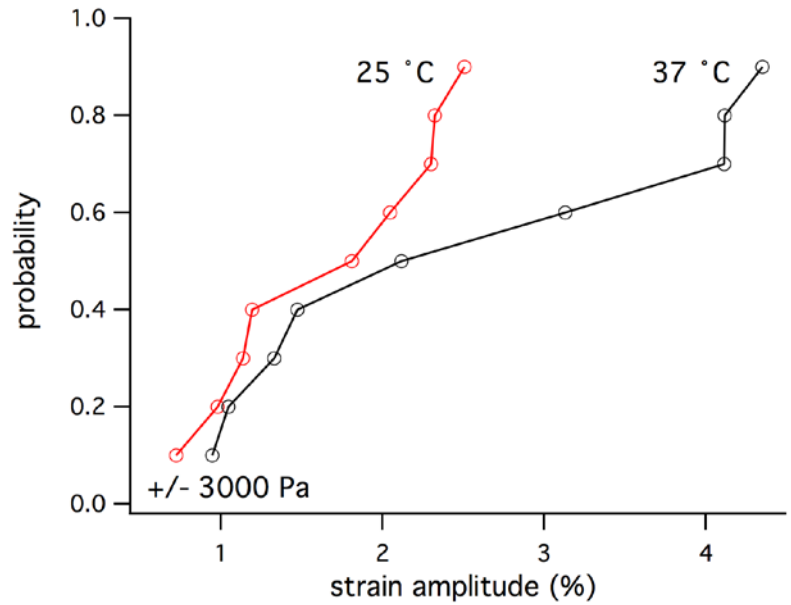


3000 DML cycles
6 ribbon failures obvious

M1212_0012

DML and fatigue measurements





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