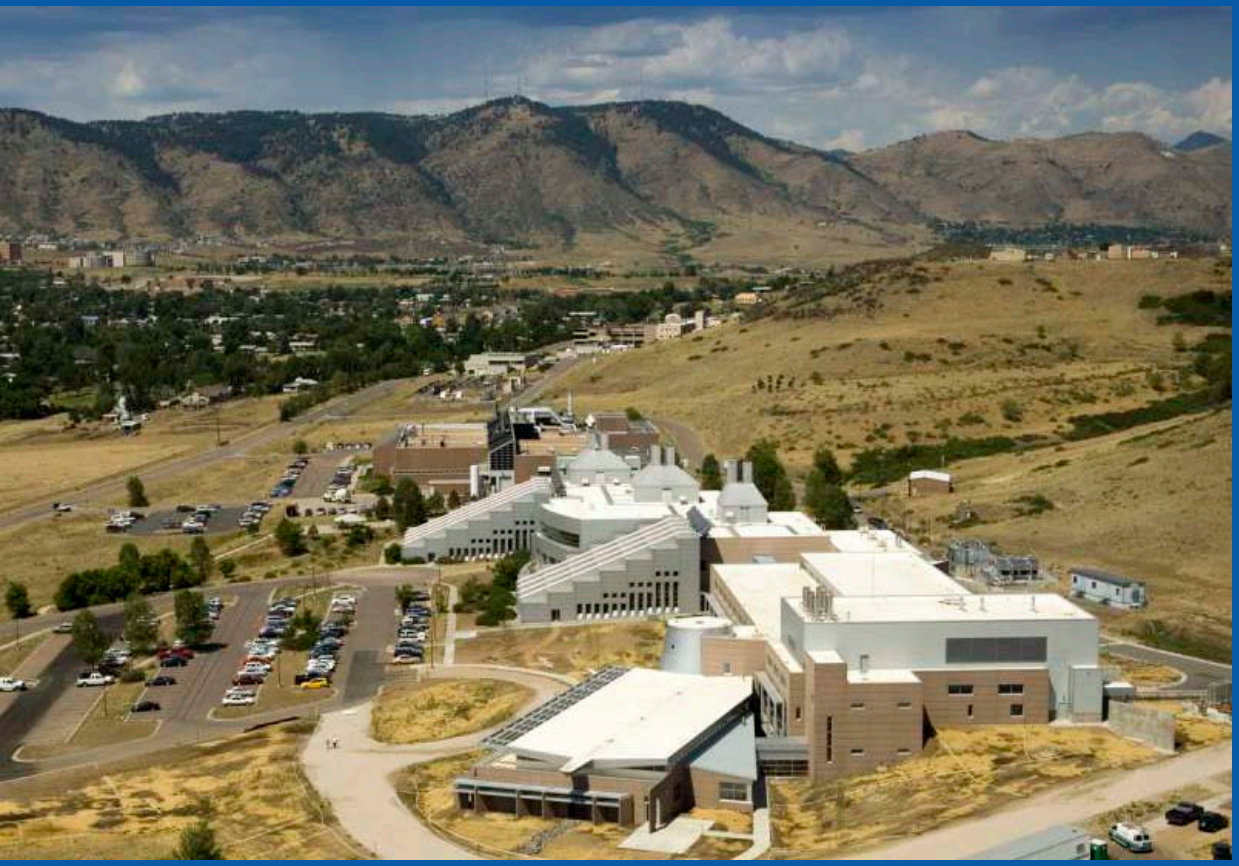
National Renewable Energy Laboratory
Innovation for Our Energy Future

National Center for Photovoltaics

Thermal and Current Cycling for CPV Qualification



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NREL PV Module Reliability Workshop
February 18-19, 2010
Golden, CO

This presentation does not contain any proprietary or confidential information.

outline

- Examination of IEC 62108 Section 10.6: Thermal Cycling
  - interpretation
  - consequence of current cycling
- Current ramp for failure detection
- Experiment and observations

IEC 62108 10.6 thermal cycling test

Table 3- Thermal cycle test options for sequence A

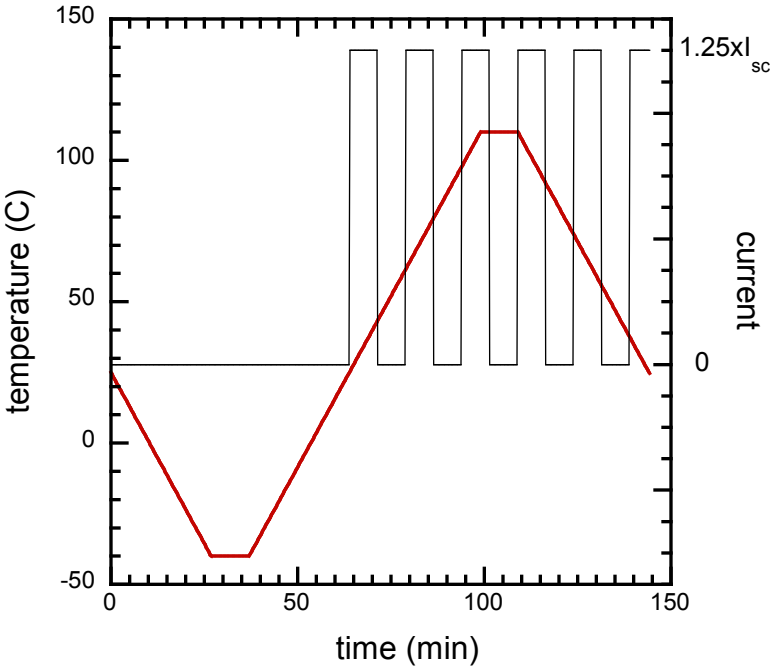
Option	Maximum cell temperature ºC	Total cycles	Applied current
TCA-1	85	1 000	Apply 1,25xI_{sc} when T>25 ºC, Cycle speed is 10 electrical/thermal
TCA-2	110	500	Apply 1,25xI_{sc} when T>25 ºC, Cycle speed is 10 electrical/thermal
TCA-3	65	2 000	Apply 1,25xI_{sc} when T>25 ºC, Cycle speed is 10 electrical/thermal

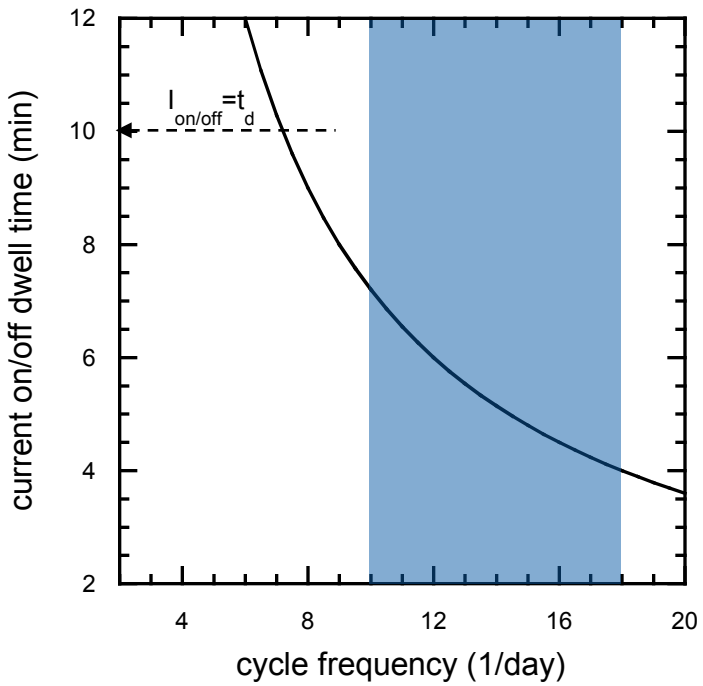
From text

“ A dwell time of at least 10 min within ±3 ºC of the high and low temperatures is required. The cycling frequency should be 10 to 18 cycles per day.”

IEC 62108 10.6 thermal cycling test

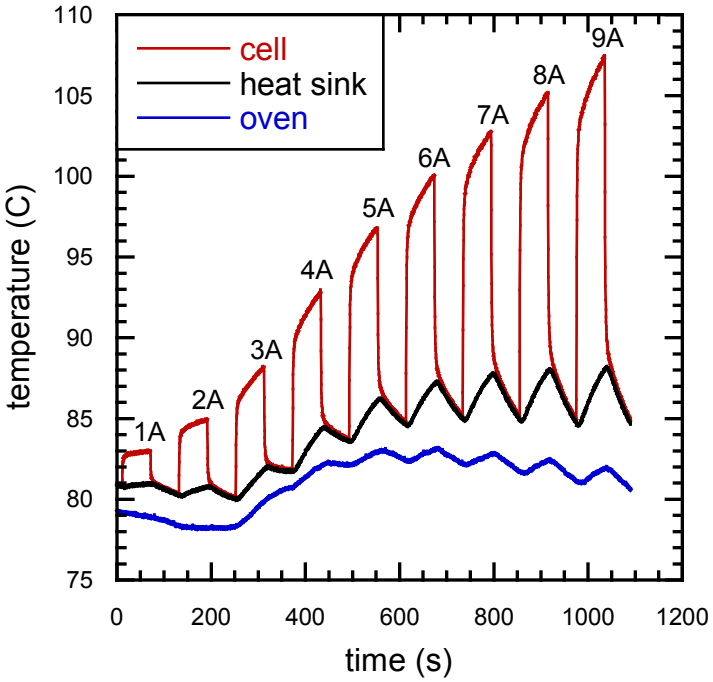
cycle frequencies

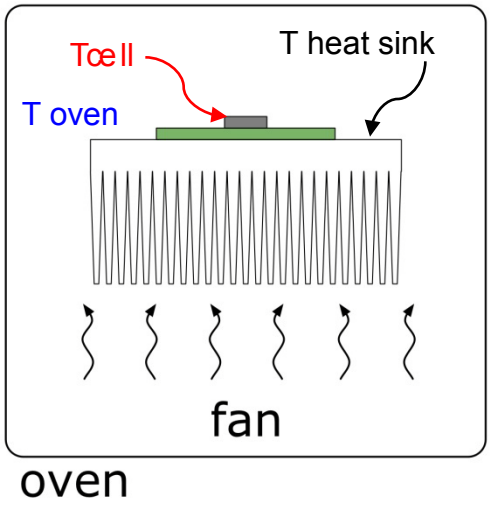




As the standard is composed, it is not possible to balance the dwell time and cycle frequency to have ONE current ON/OFF cycle coincident with the hot temperature dwell time.

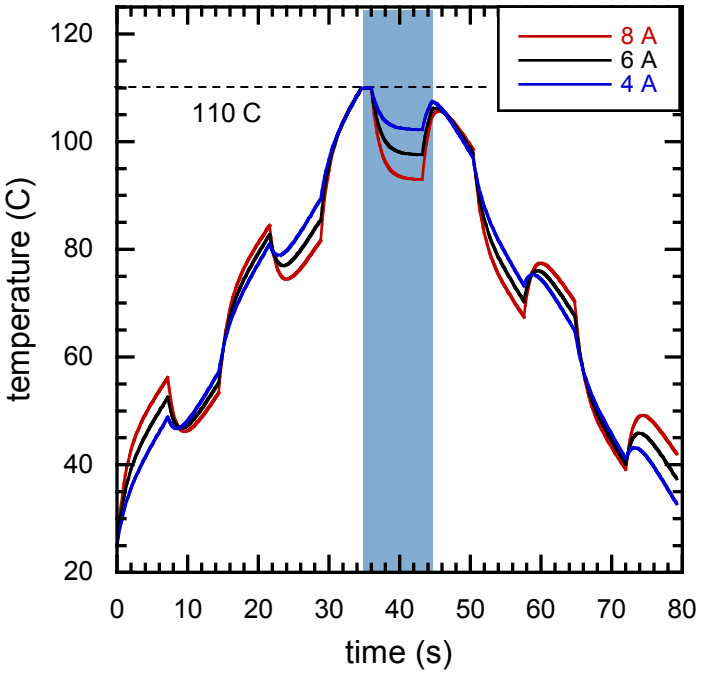
heating experiments

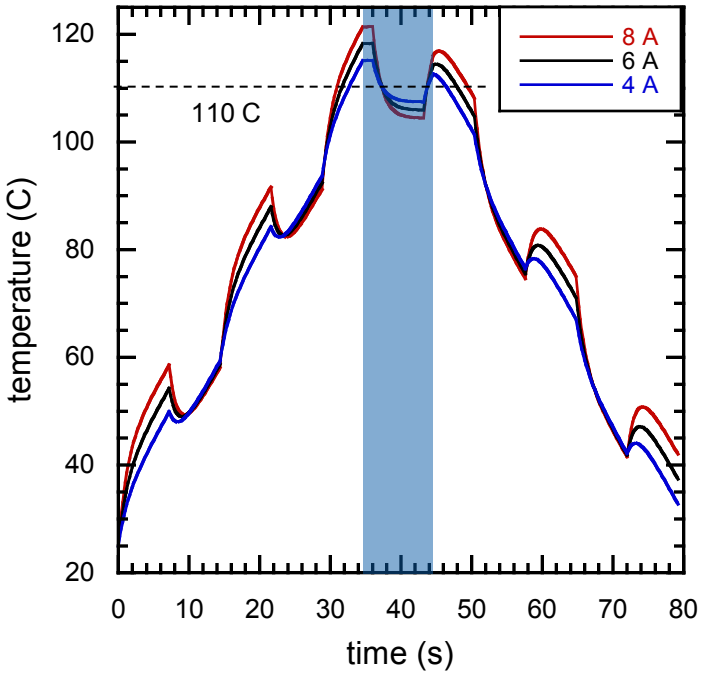




An immediate, and significant, temperature rise is experienced by the cell upon application of current.

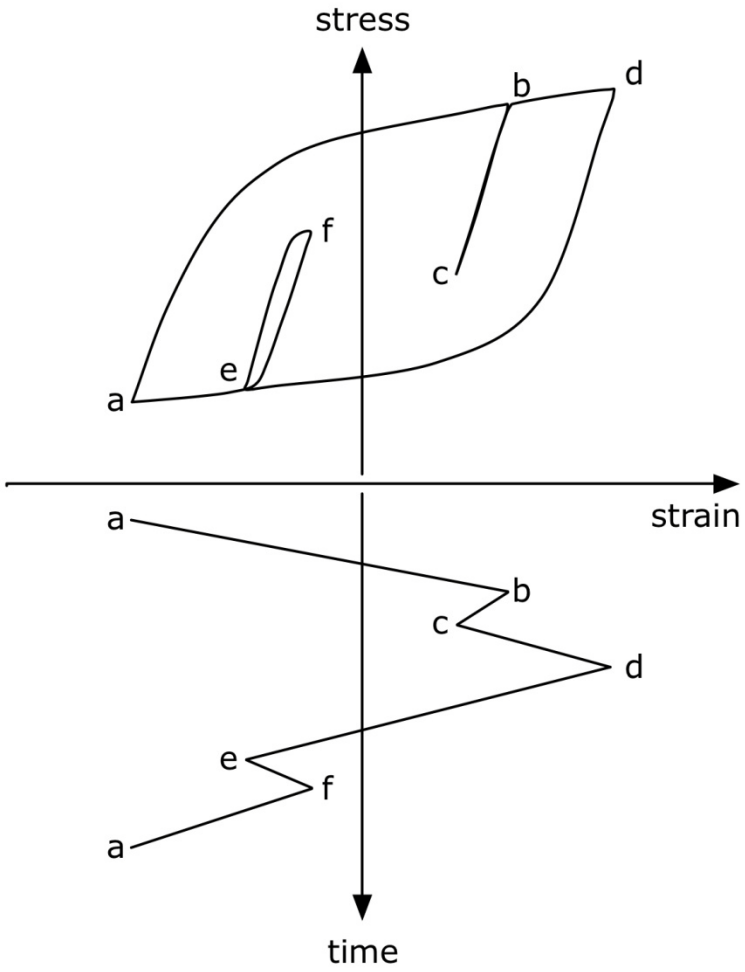
heating experiments





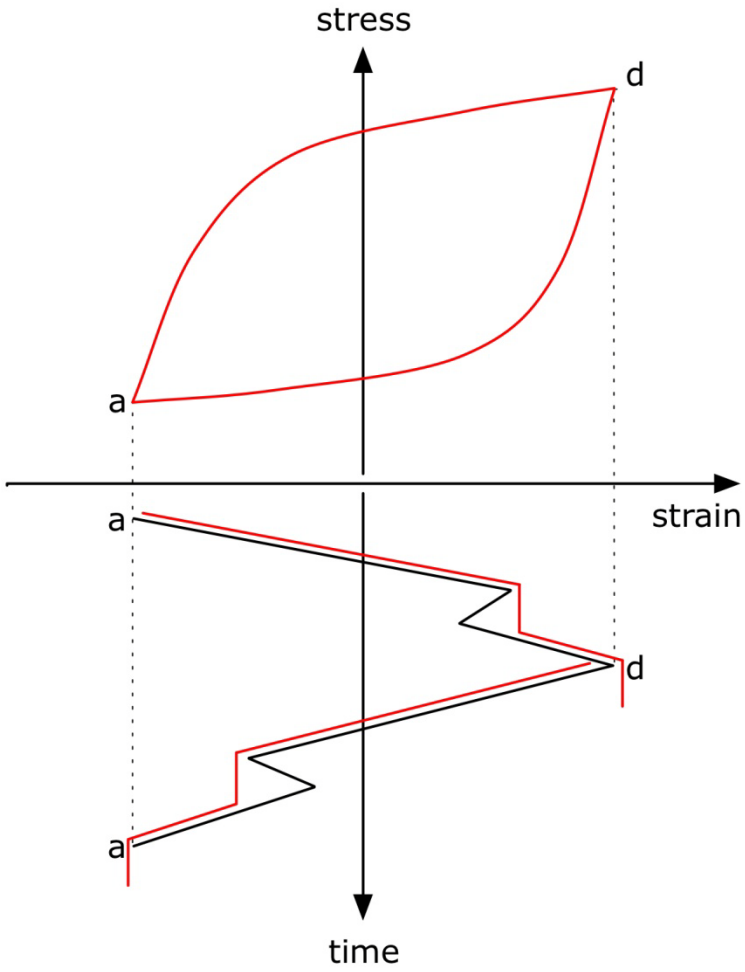
Cell temperature with current cycling is modeled for a dwell maximum and mean of 110 C at 4, 6, and 8A.

cycle damage



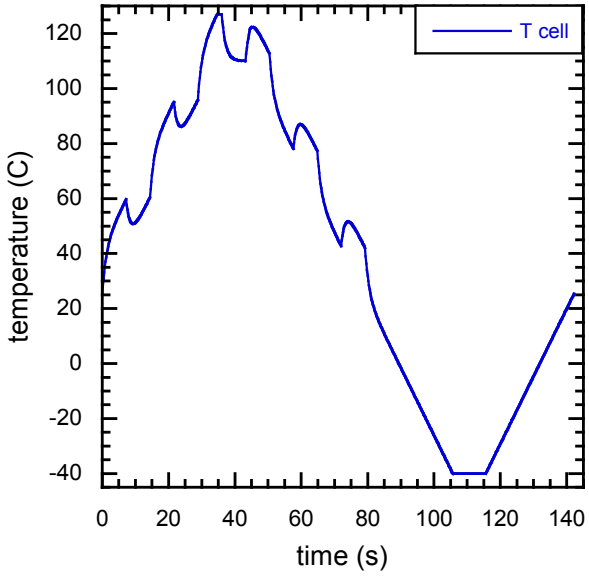
- Area within the stress-strain hysteresis is the work, or damage, imparted through the cycle.
- Small reverses in loading do not affect the hysteresis area and therefore the work done.

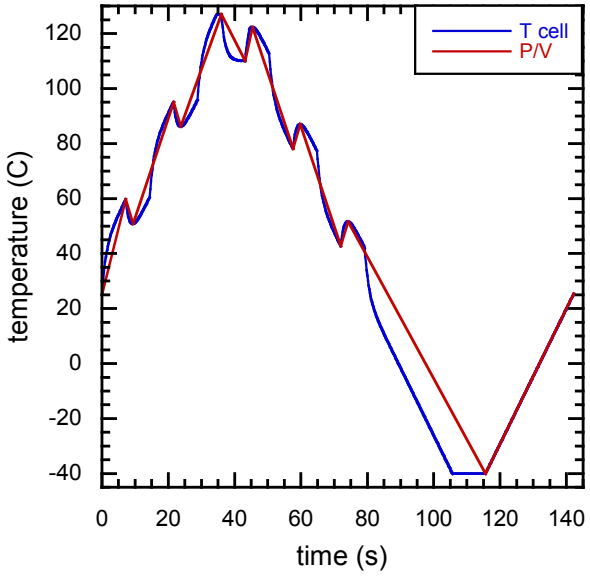
cycle damage

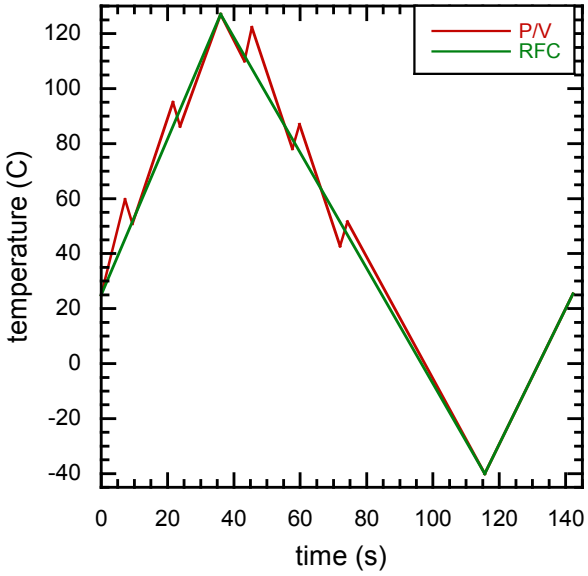


- Area within the stress-strain hysteresis is the work, or damage, imparted through the cycle.
- Small reverses in loading do not affect the hysteresis area and therefore the work done.
- The rainflow method “reaps” smaller cycles contained within larger ones,

cycle damage

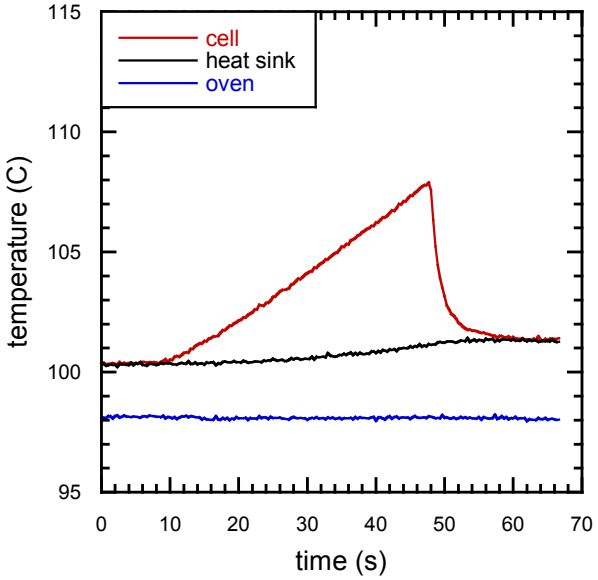


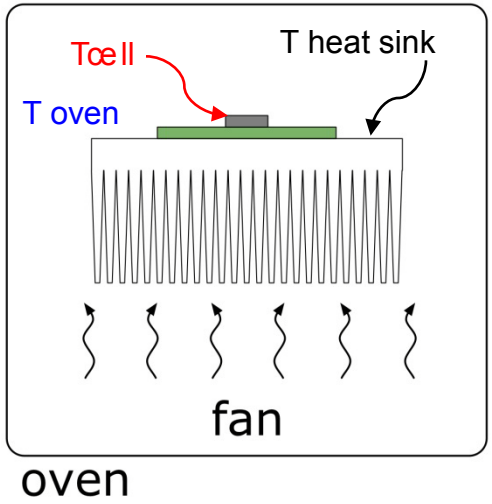


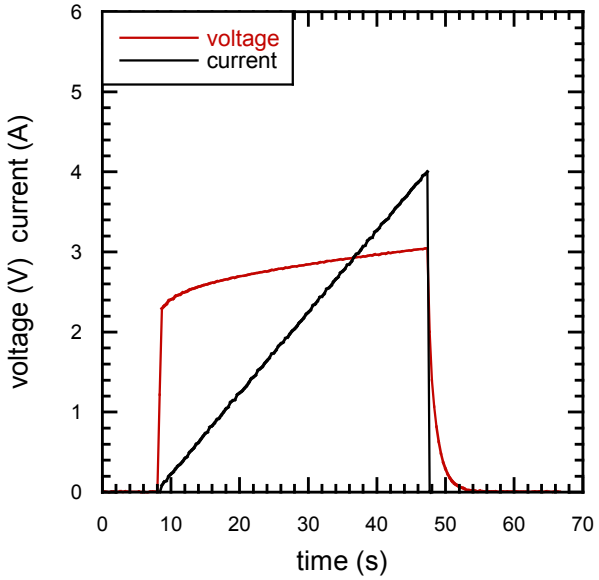


A rainflow count applied to the modeled temperature resulting from current cycling demonstrates no additional damage due to the extra fluctuations in temperature.

failure detection

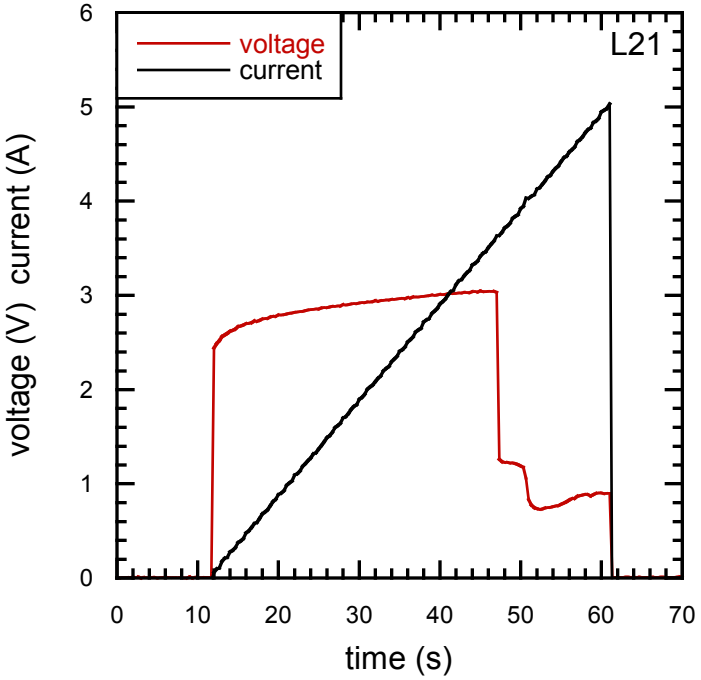






A 4A current ramp is designed to replicate thermal cycling conditions.

failure detection

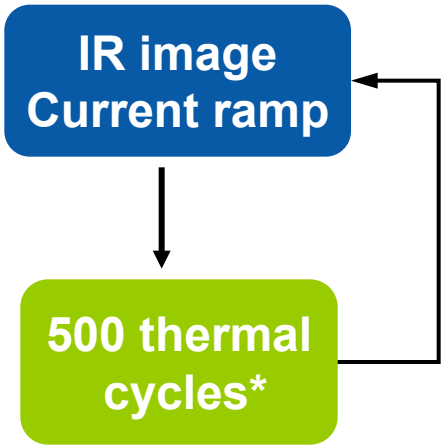


cell assembly survived 2175 NREL thermal cycles (3A max, no heat sink)

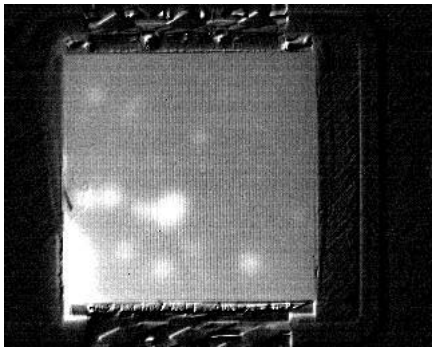
failure occurs at ~3.63A

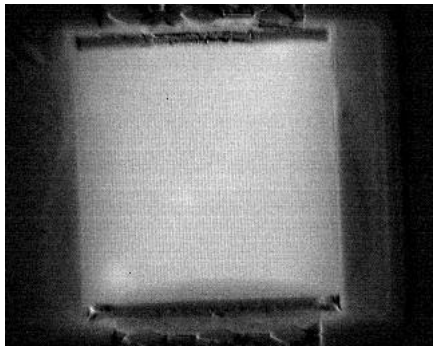
thermal cycling

Experiment:



Initial IR images show varying degree and location of voids





Non of the initial 17 assemblies failed the 4 A current ramp

$T_{min} = -40C$

$T_{max} = 110C$

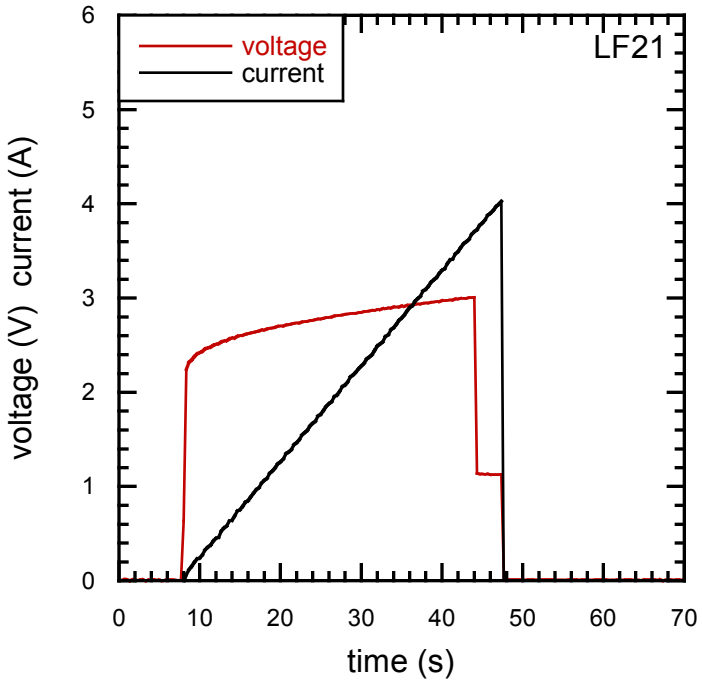
$t_d = 5\,\text{min}$

$f = 48/day$

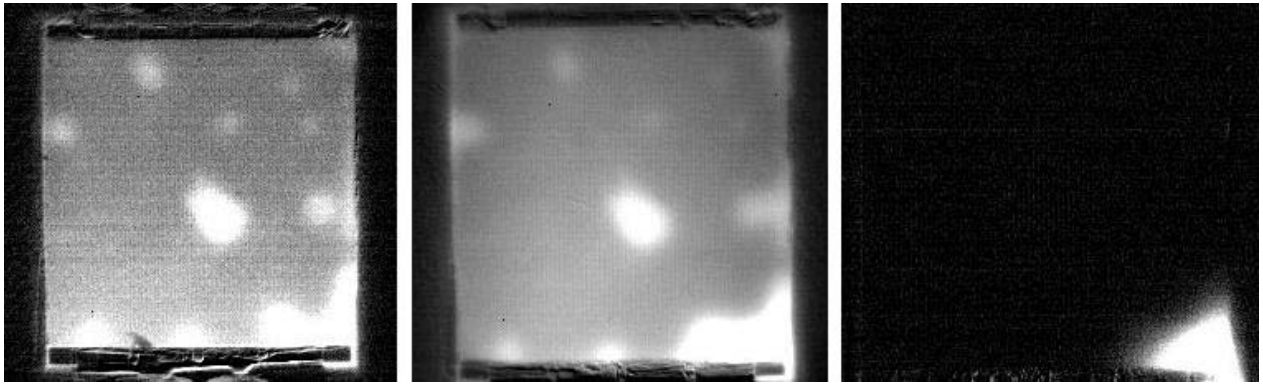
- Samples consist of ~ 1cm^2 multi-junction cell on ~2 x 2 cm substrate
- Cell assembly heating is via the application of forward bias current, I_{max} = 3A

*Bosco, N.S., Sweet, C.,Kurtz, S., "Reliability Testing the Die-Attach of CPV Cell Assembles", 34th IEEE Photovoltaic Specialists Conference, 7-12 June 2009, Philadelphia, Pennsylvania

thermal cycling

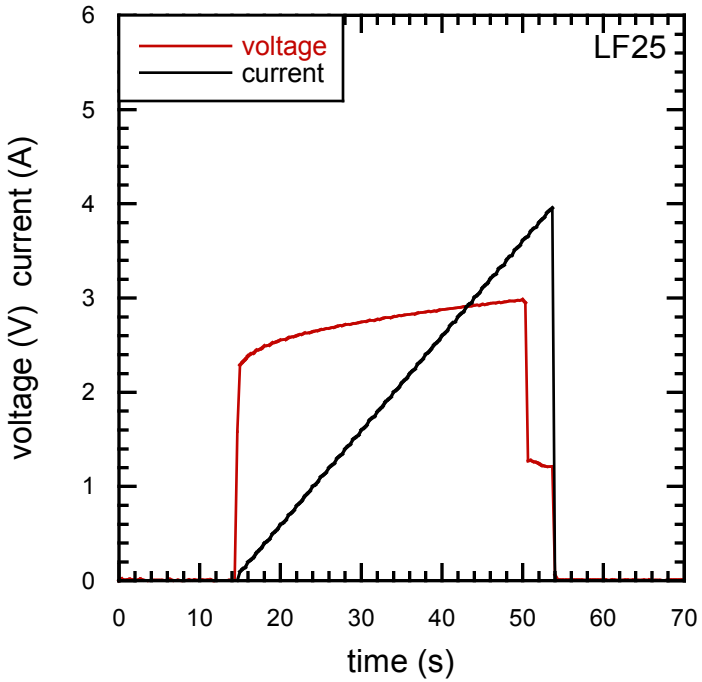


Following 500 cycles, one assembly failed the current ramp

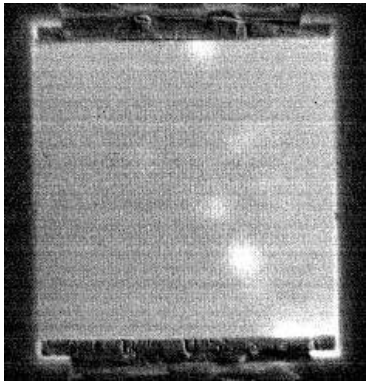


initial 500 cycles failure

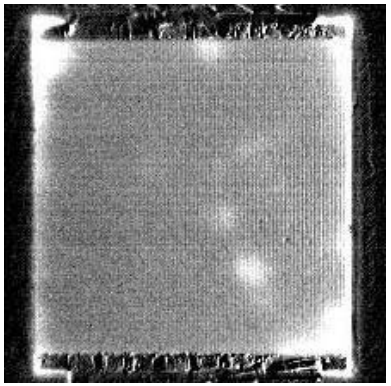
thermal cycling



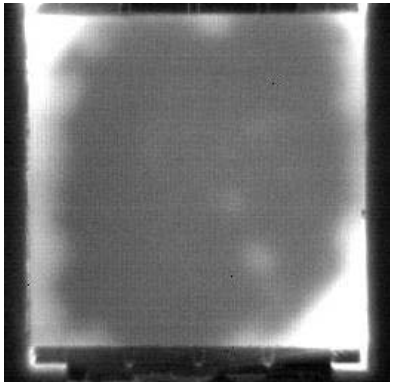
Following 1000 cycles, 4 assemblies failed the current ramp



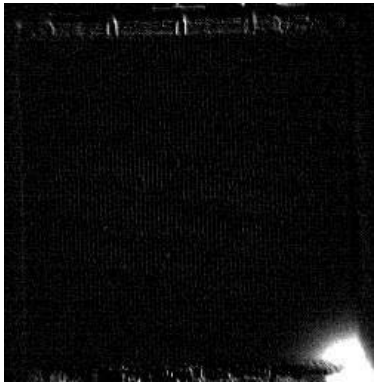
initial



500 cycles



1000 cycles

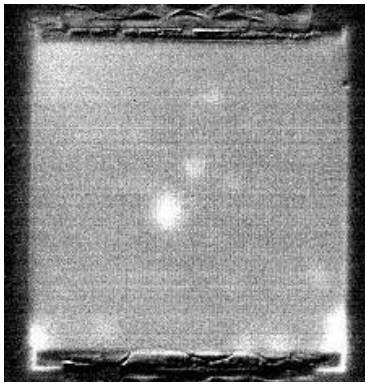


failure

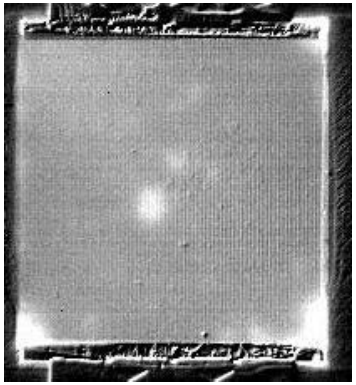
thermal cycling

Additional samples demonstrate increased cracking with cycling, though survive the 4A current ramp

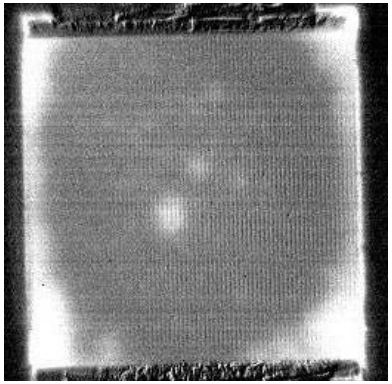
LF15



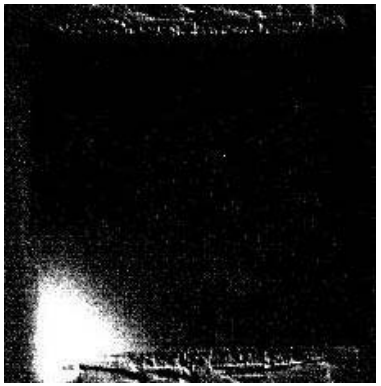
initial



500 cycles



1000 cycles

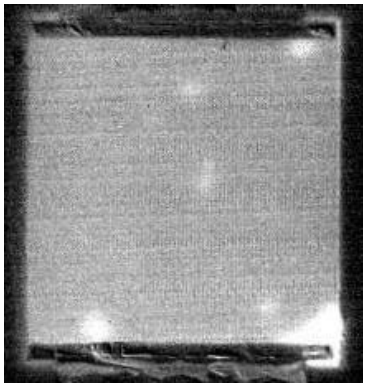
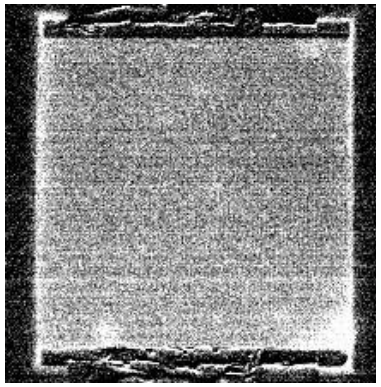
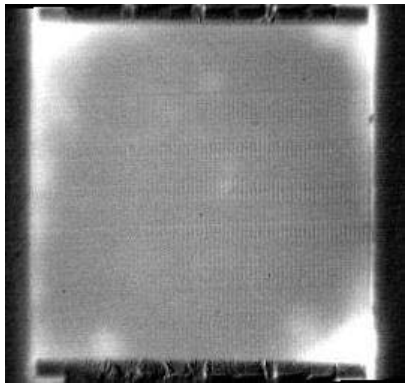
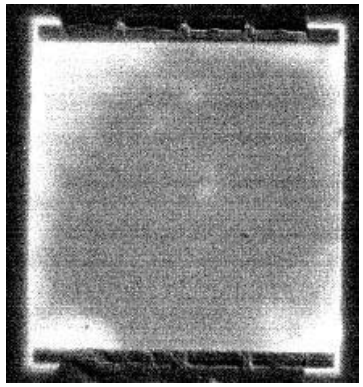


1303 cycles

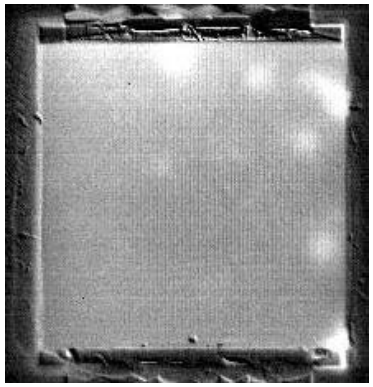
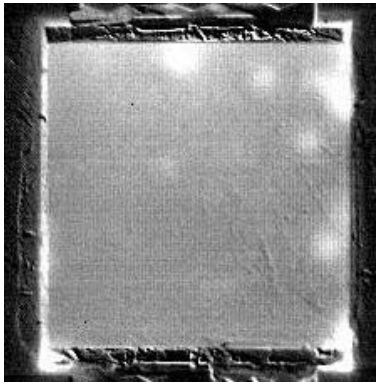
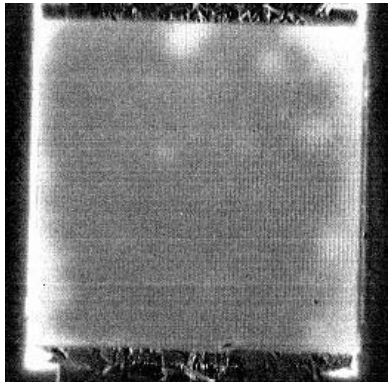
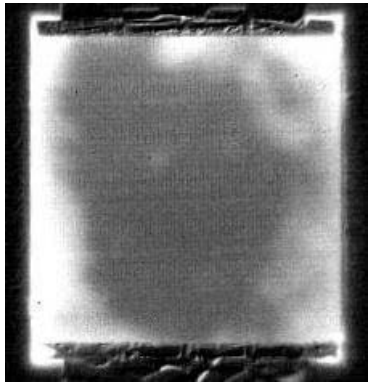
thermal cycling

Additional samples demonstrate increased cracking with cycling, though survive the 4A current ramp

LF4

LF10

initial | 500 cycles | 1000 cycles | 1500 cycles

conclusions

- IEC 62108 Section 10.6: Thermal Cycling cannot be executed as written.
- Additional temperature excursions due to current cycling does not accelerate damage.
- Current application up to 4A/cm^2 is benign to the cell though will cause failure if large cracks/voids exist under bus-bar.
  - Not representative of on-sun failures
  - Unacceptable amounts of and sized voids/cracks not detected through failure

proposals

- Proposed amendments to IEC 62108 Section 10.6: Thermal Cycling
  - Current application should be reduced to when T>25 C (similar to IEC 61215).
  - Cell current density level should be reduced to 4 A/cm^2 or J_{sc}.
  - Additional requirement should limit the percentage of voids/cracks as detected via an appropriate imaging technique. Alternatively, modules should be subject to an on-sun exposure for a designated time and irradiance.

and future work

- On-sun evaluation of voided and cracked die attach.