Accelerated Testing and On-Sun Failure of CPV Die-Attach

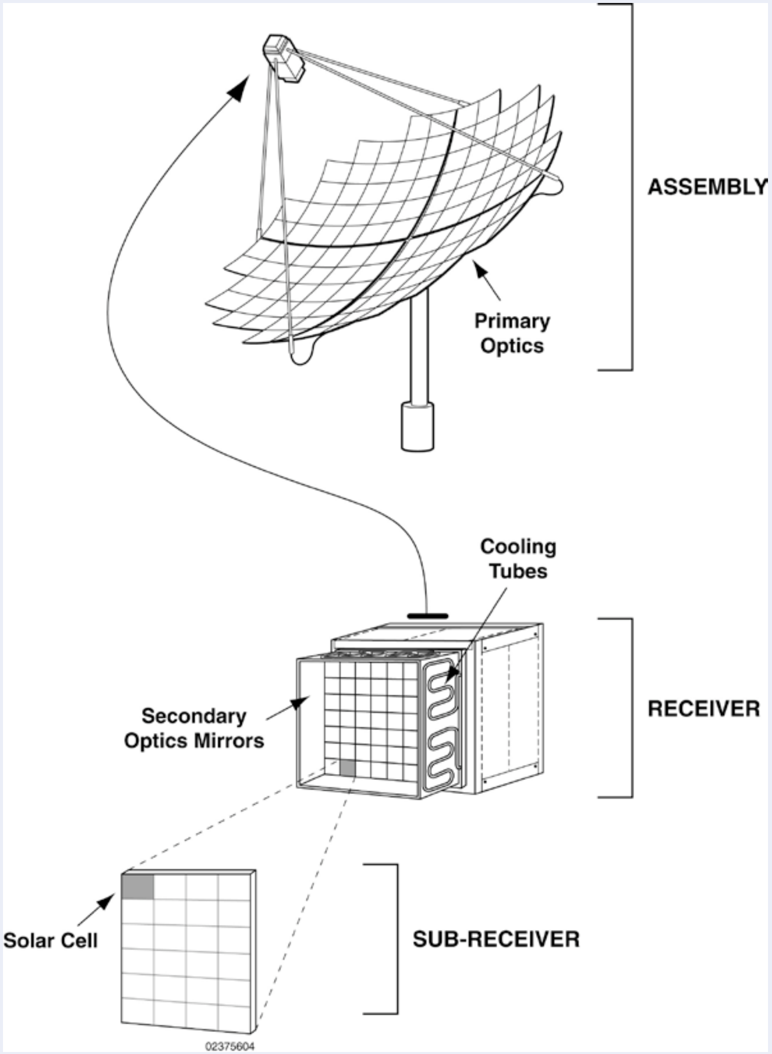
Nick Bosco, Sarah Kurtz, and Adam Stokes

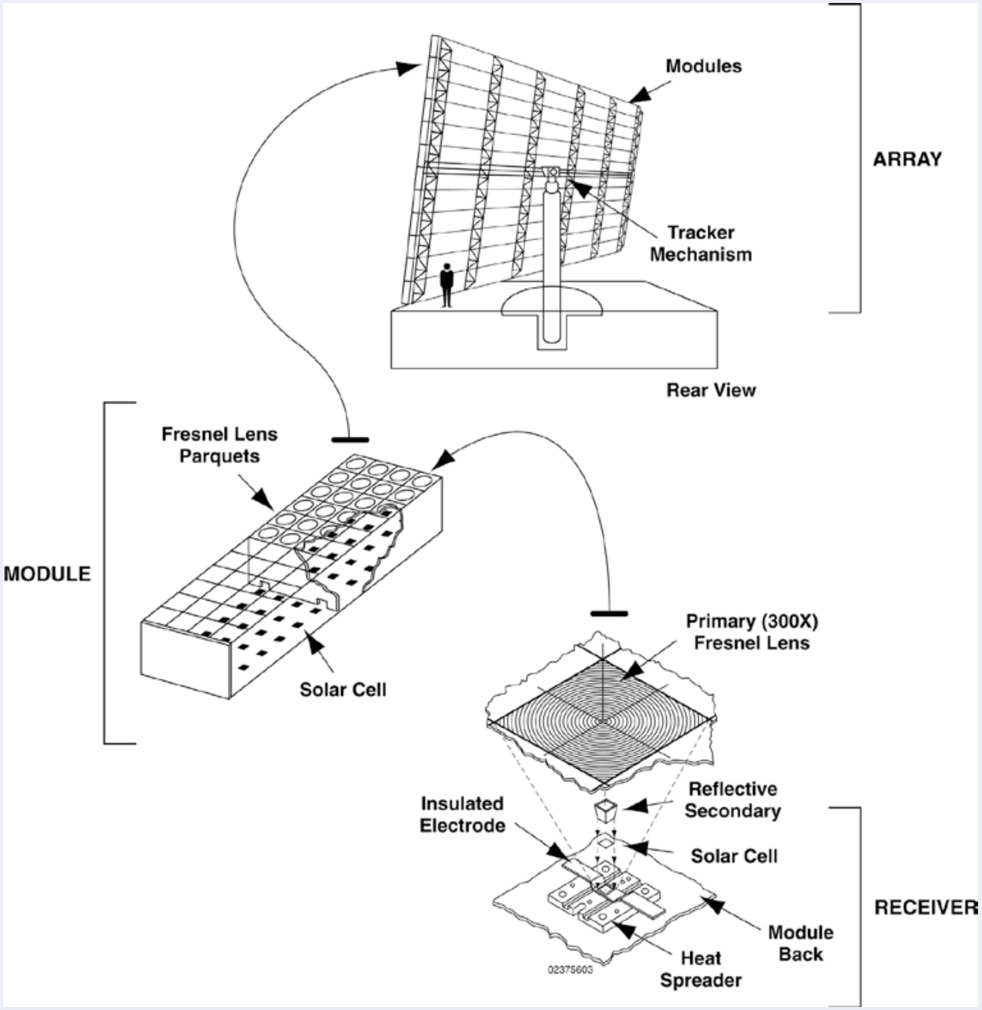
National Renewable Energy Laboratory
Golden, CO

Presented at the 2010 Workshop on Accelerated Stress Testing and Reliability, 8-9 October 2010, Denver, Colorado

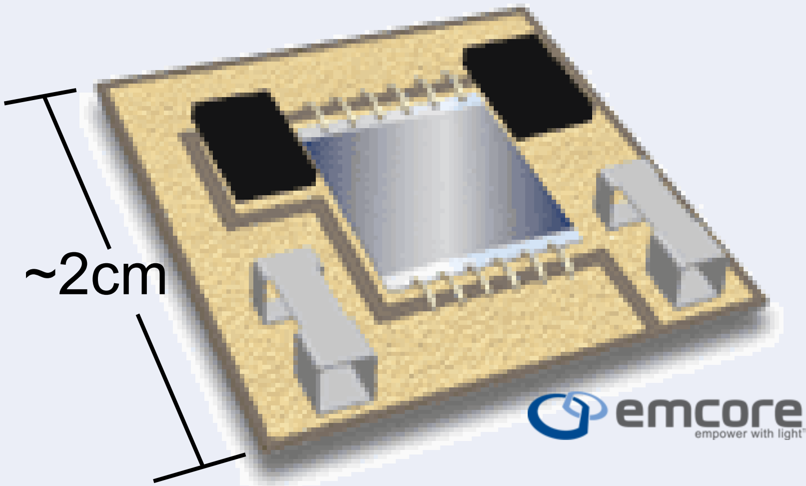
NREL/PR-5200-49243

Introduction: CPV concepts

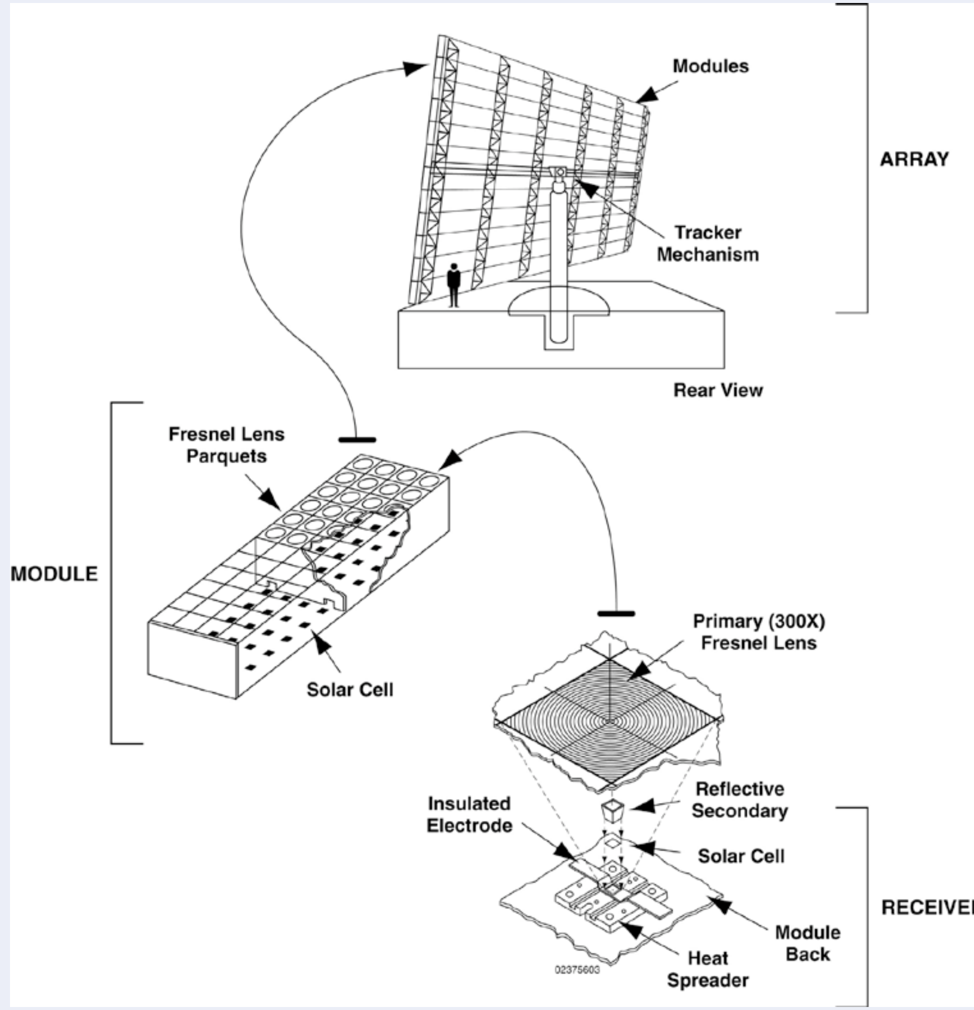




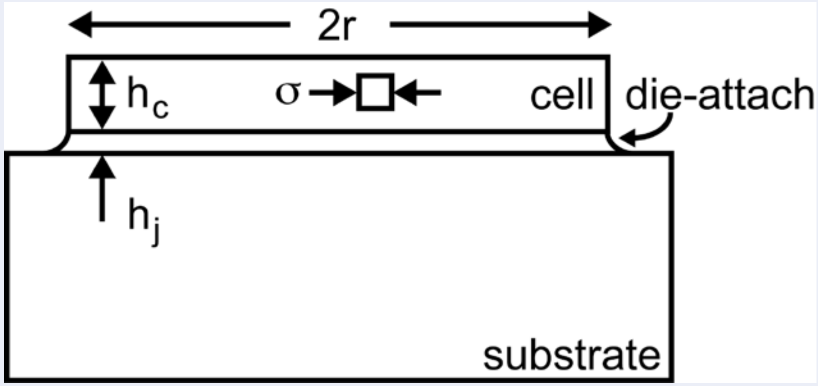
Introduction: CPV concepts



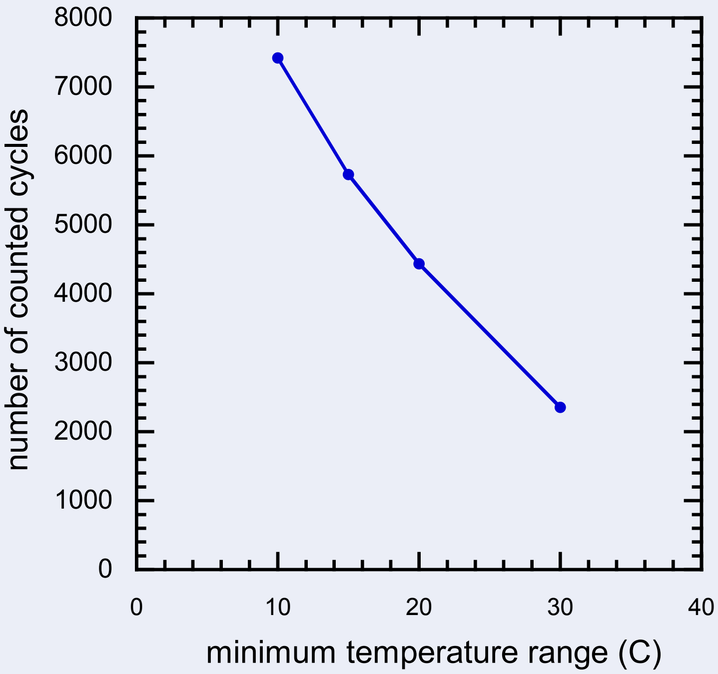
- 500-1000x concentration
- DNI = 1000 W/m^2
- η ~ 39%
- Q = 30-60 W



die-attach and temperature changes



$$\sigma_o = \frac{E_c \Delta\alpha \Delta T}{(1-\upsilon_c)}$$

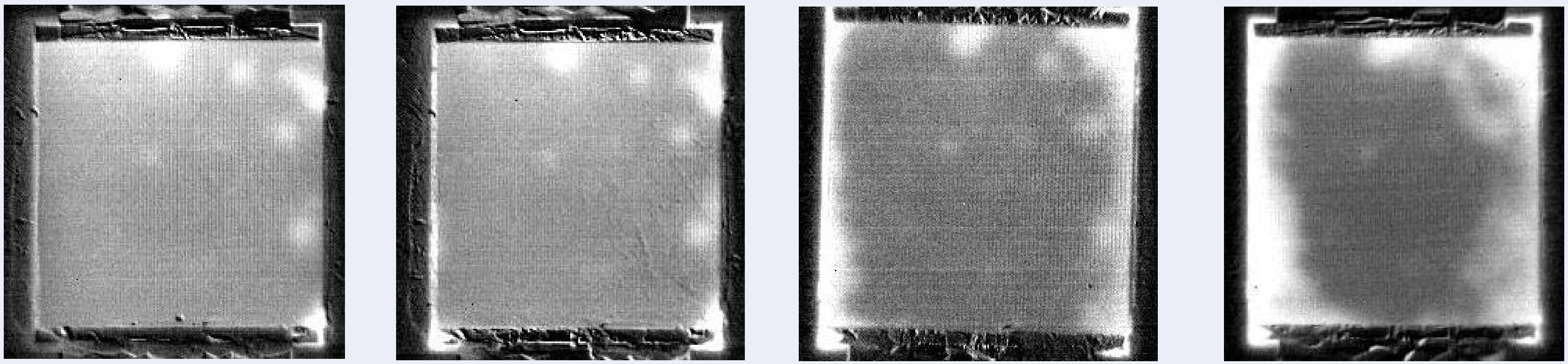


Stress in the die attach is directly related to the magnitude of temperature change

In Golden, CO over 4000 temperature changes of > 20 C are experienced each year

thermal fatigue

Thermal fatigue will cause die-attach cracking ultimately leading to cell failure via thermal runaway



initial 500 cycles 1000 cycles 1500 cycles

infrared imaging of CPV cell through thermal cycling

Has this sample failed?

motivation

Determine reliability

→ test to failure

→ induce and recognize a representative failure

Where we started

IEC 62108 design qualification and type approval

thermal

↓

Dark I-V

issue: will this sequence induce and recognize a representative failure?

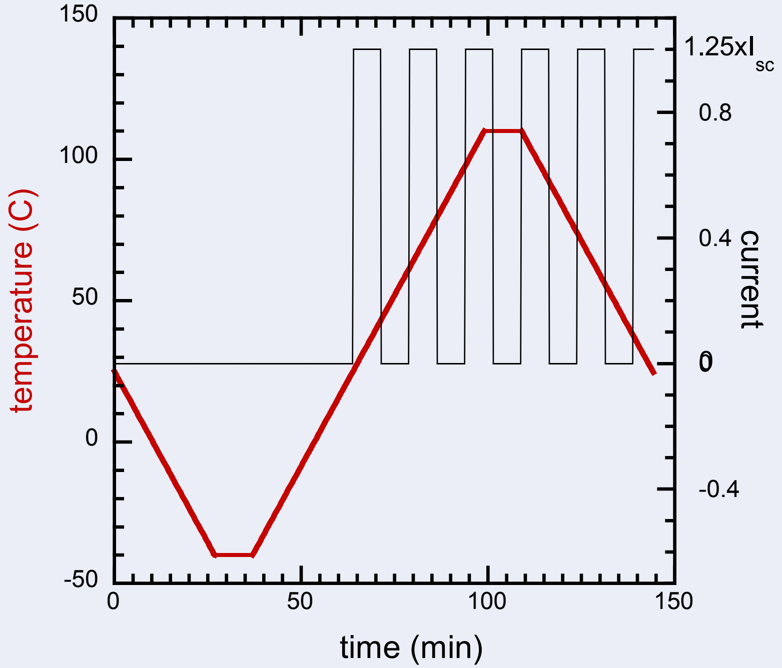
motivation

Outstanding issues:

- Can thermal cycling produce enough damage to precipitate a representative failure?
- If produced, would that damage cause failure through testing?
- How much damage is required to cause this representative failure?

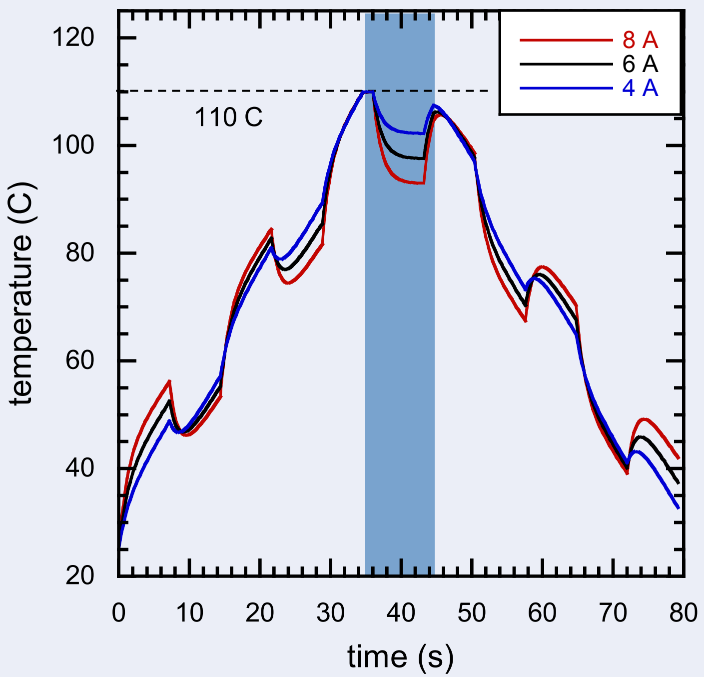
- Can the application of current simulate an on-sun failure
- If so, what level of current is appropriate?
  - benign to a "healthy" die-attach
  - will cause cell failure in a "failed" die-attach

IEC 62108 10.6



Thermal cycling parameters as set by the IEC standard:

Applied currents approaching Isc are commonly believed to induce un-representative cell failure



Simulated cell temperature response for 3 levels of forward bias

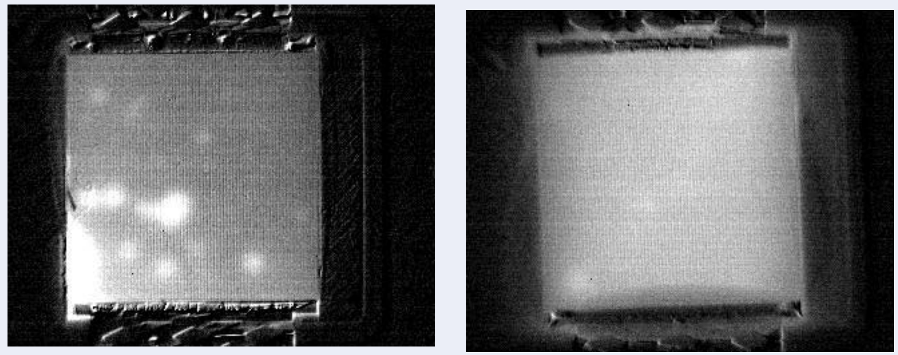
experiment

IR image
Current ramp
On-sun exposure

↓

500 thermal cycles*

Initial IR images show varying degree and location of voids



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

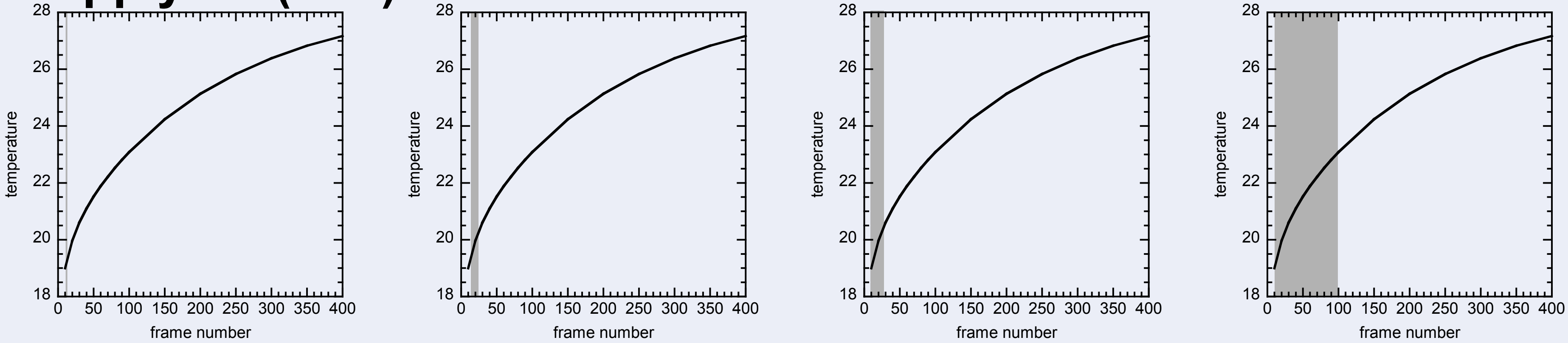
$$T_{\text{min}} = -40C$$
$$T_{\text{max}} = 110C$$
$$t_d = 5\,\text{min}$$
$$f = 48/day$$

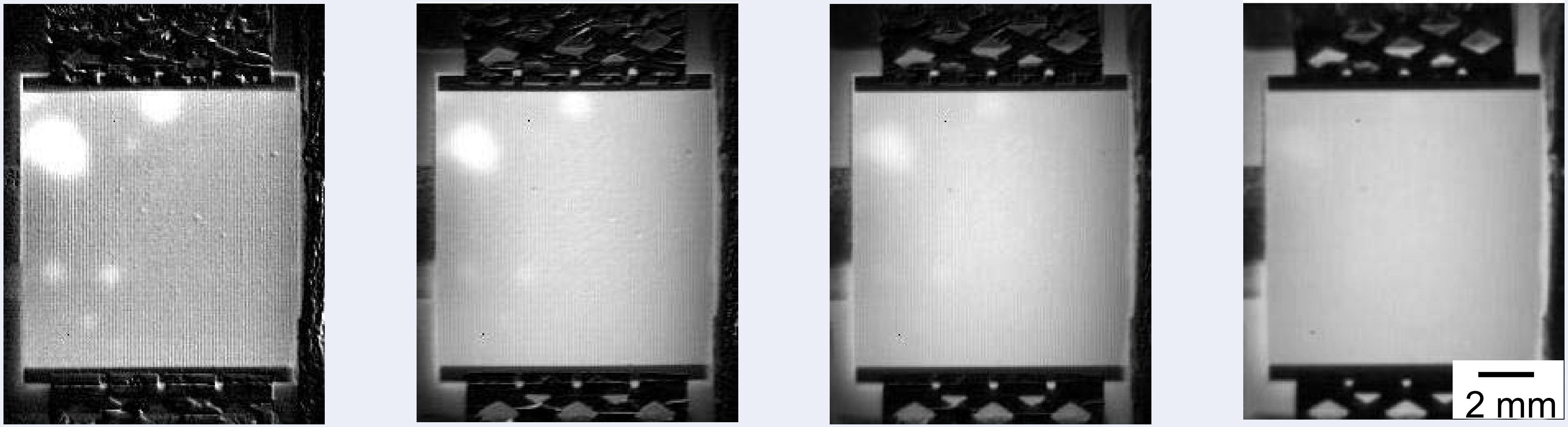
- Samples consist of ~ 1cm^2 multi-junction cell on ~2 x 2 cm substrate
- Cell assembly heating is via the application of forward bias current, I_{max} = 3A

*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

IR imaging

Apply 2A (~4V) and record an IR “video”

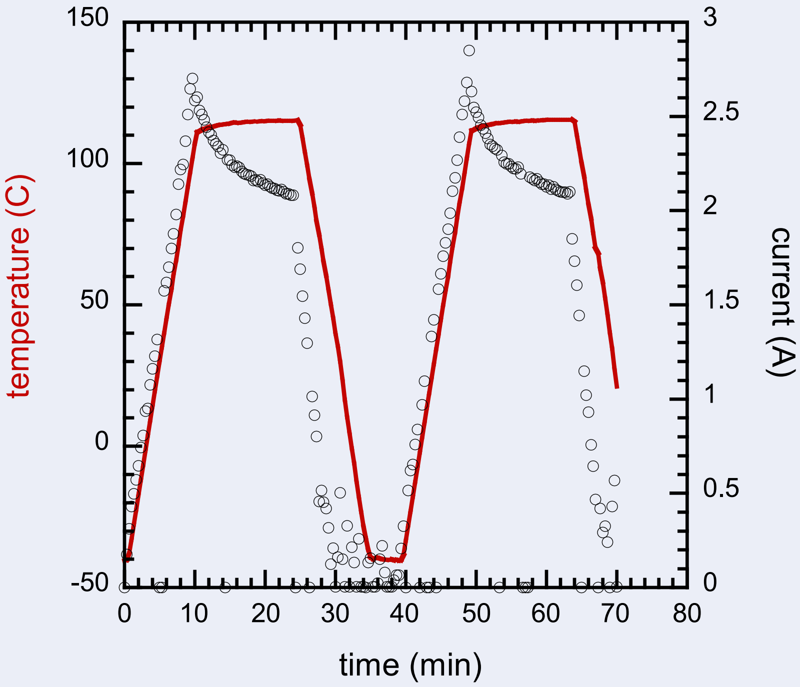




Δt = 20 ms Δt = 100 ms Δt = 200 ms Δt = 2000 ms

thermal cycling

Forward bias heating current and temperature response

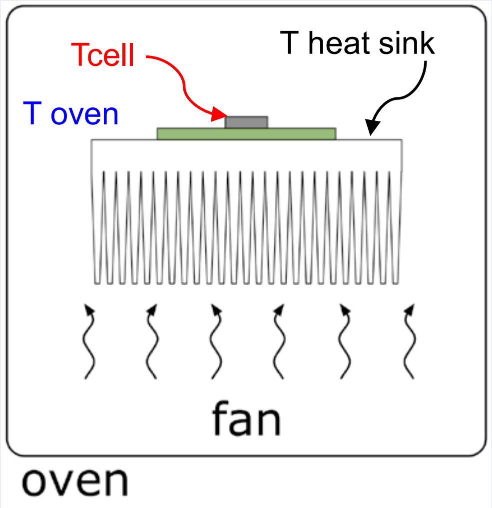


Max current of ~3A

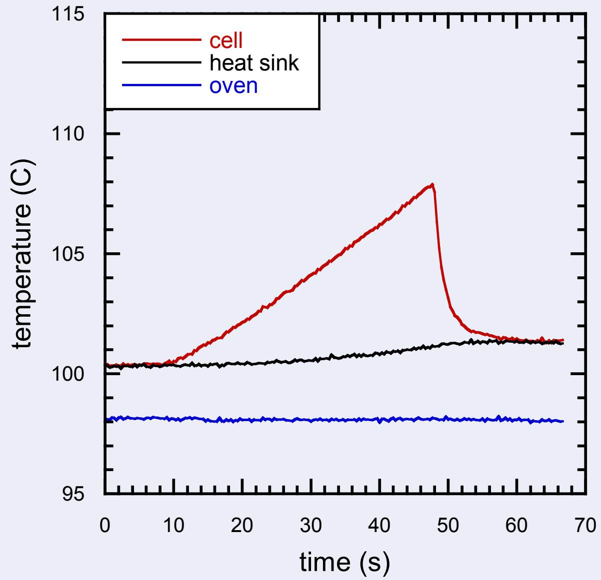
Excellent temperature control

current ramp

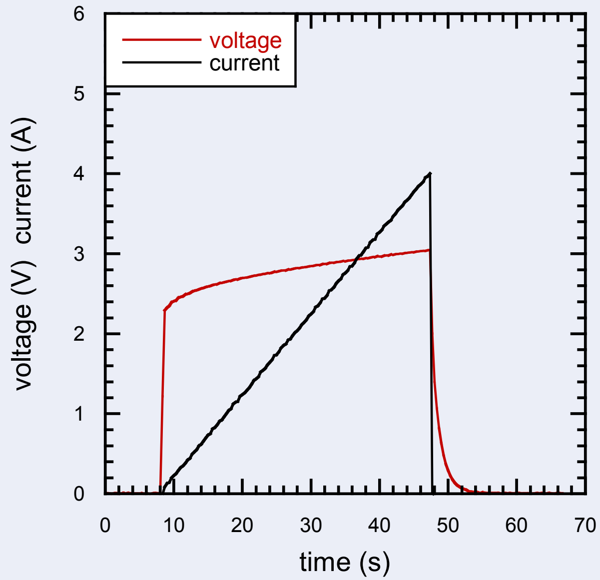
4A current ramp designed to replicate cycling conditions



Experimental set-up



Temperature response



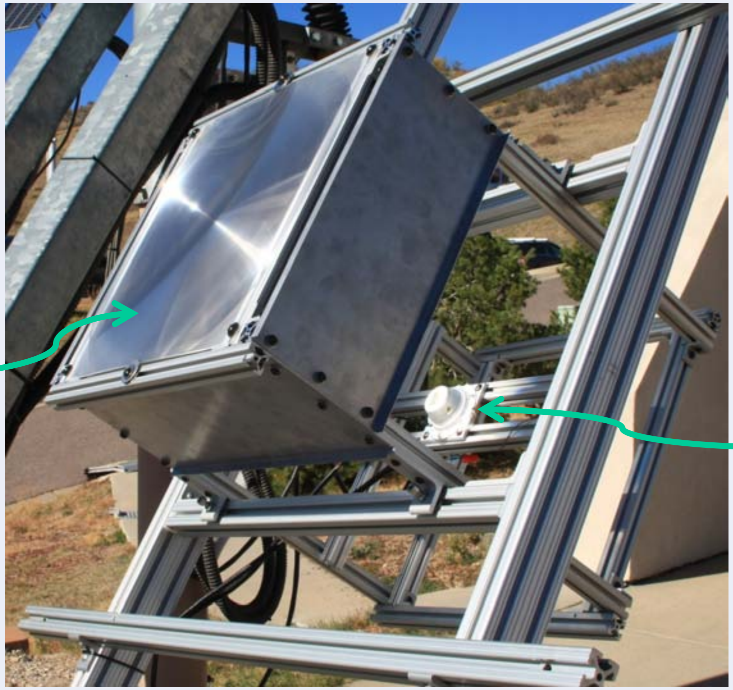
I V response

on-sun exposure

Sample heat-sunk and exposed to ~1000x concentration

2-axis tracker

~1000x Fresnel lens

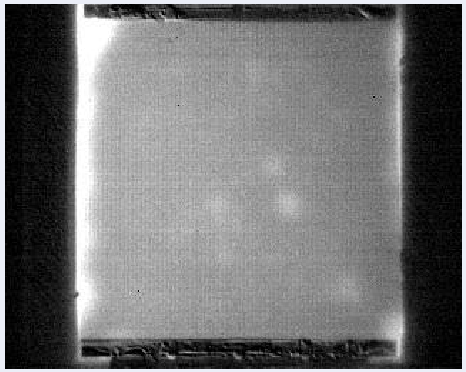


Fixtured cell assembly

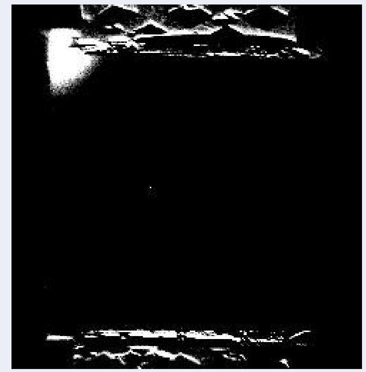
Open circuit Voltage monitored during exposure

thermal cycling failures

LF18

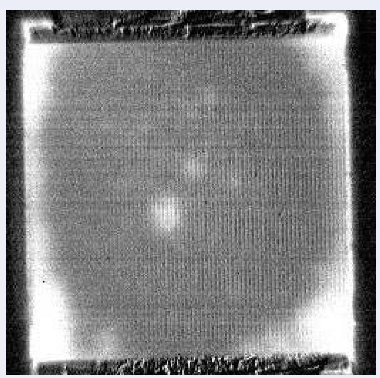


500 cycles

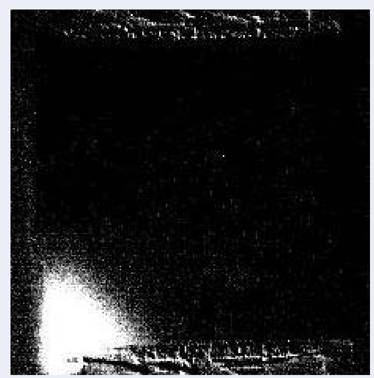


shorted at N=806

LF15



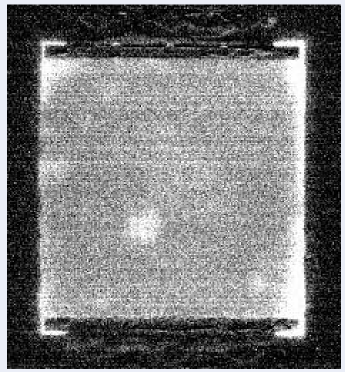
1000 cycles



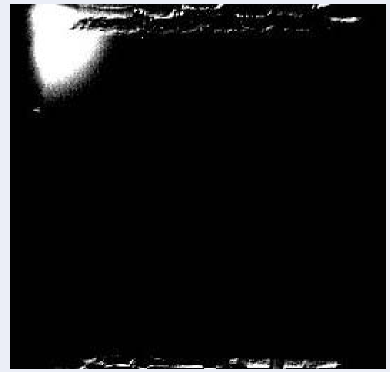
shorted at N=1303

IR imaging failures

LF11

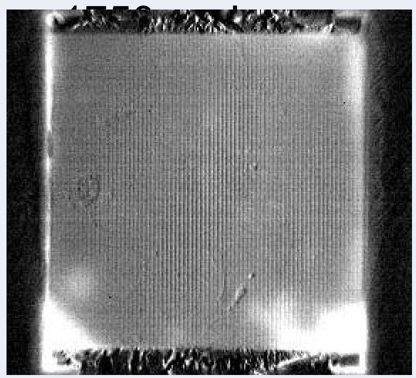


500 cycles



1000 cycles
failed in IR imaging

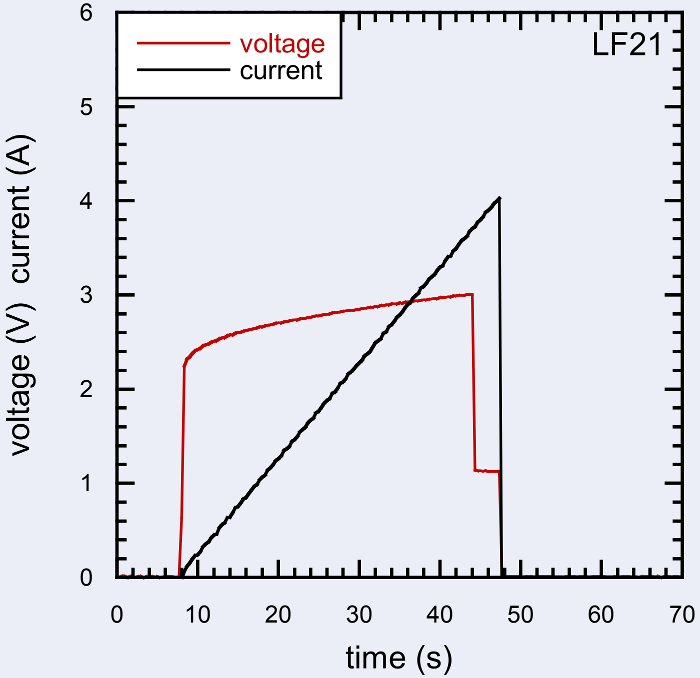
LF7

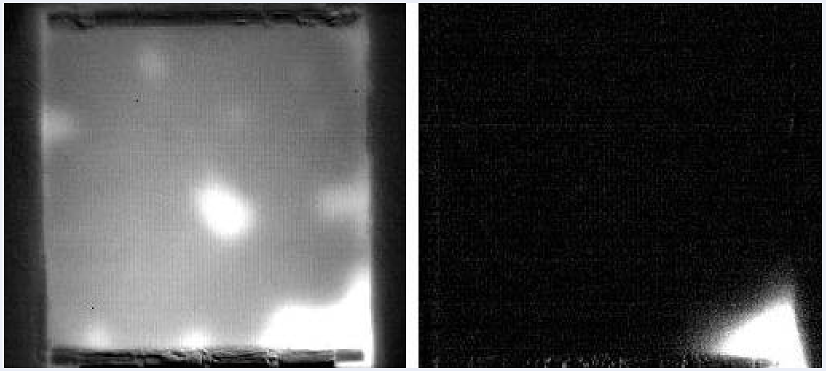


500 cycles

1000 cycles
failed in IR imaging

current ramp failures



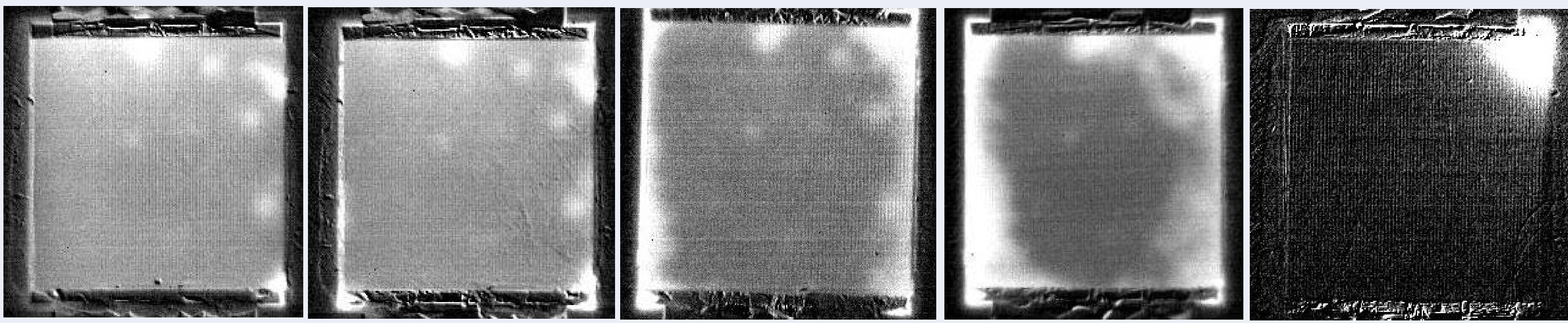


500 cycles

Failed current ramp @ 3.4A

on-sun failure

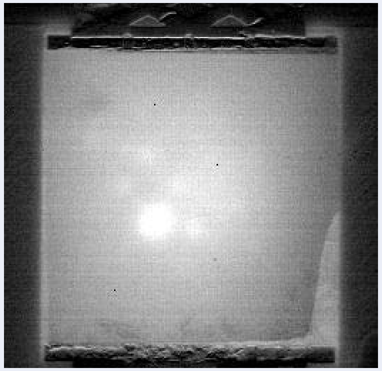
initial | 500 cycles | 1000 cycles | 1500 cycles



I ramp: passed | I ramp: passed | I ramp: passed | I ramp: passed | failed on-sun

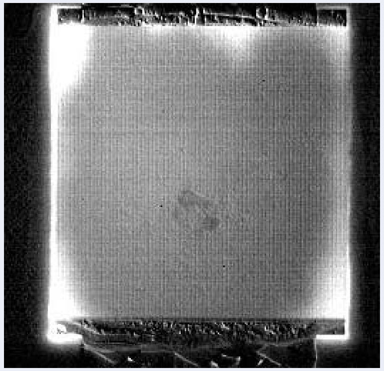
thermal cycling

LF26



250

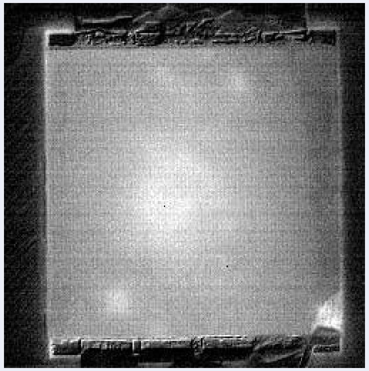
LF9



1250

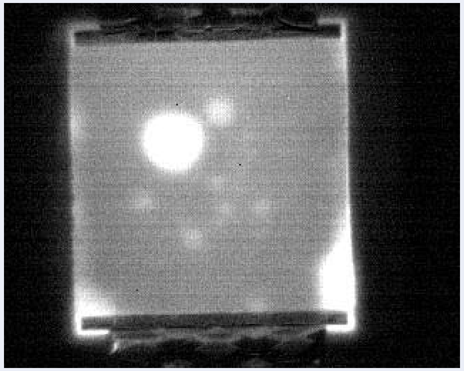
These samples have passed on-sun screening and continue to be cycled

LF1



250 cycles

LF23



1250

thermal cycling

Summary of Results

Sample ID	N=250	N=500	N=1000	N=1250	N=1500	N=1750
LF1	IR passed on-sun					
LF5	IR passed on-sun					
LF26	passed on-sun					
LF21		IR failed I ramp @3.4A				
LF20			failed @ IR imaging			
LF30			failed @ IR imaging			
LF11			failed @ IR imaging			
LF18			shorted at N=806			
LF28			failed @ IR imaging			
LF3			IR failed I ramp @3.4A			
LF7			failed @ IR imaging			
LF25			IR failed I ramp @3.6A			
LF23				passed on-sun		
LF9				passed on-sun		
LF29				passed on-sun		
LF8				IR failed on sun		
LF15					shorted at N=1303	
LF19					shorted at N=1262	
LF17					IR failed I ramp @ 3.4A	
LF10					IR ramp failed on sun	
LF4						IR failed on sun

thermal cycling

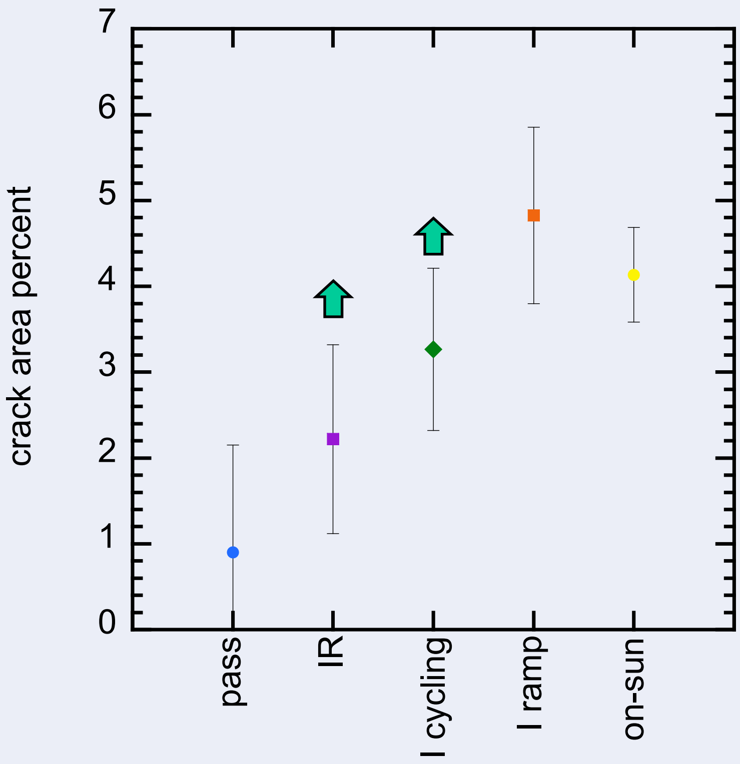
Summary of Results: sorted for increasing crack damage

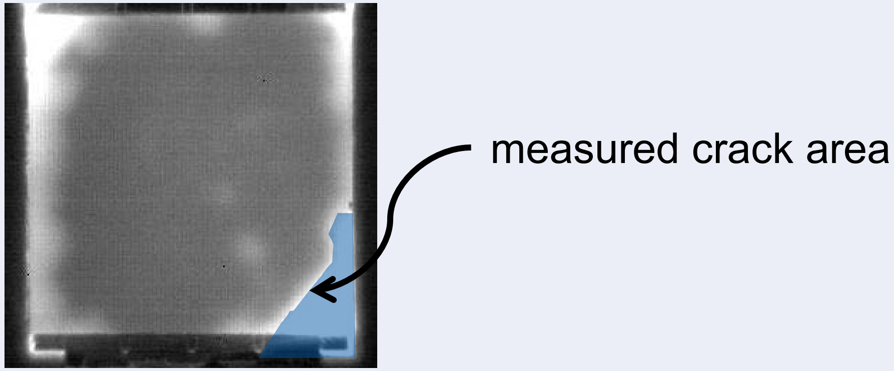
Sample ID	N=250	N=500	N=1000	N=1250	N=1500	N=1750	corner crack %
LF1	IR passed on-sun						0
LF5	IR passed on-sun						0
LF26	passed on-sun						0
LF23				passed on-sun			0.4
LF20			failed @ IR imaging				1.2
LF30			failed @ IR imaging				1.4
LF11			failed @ IR imaging				1.8
LF18			shorted at N=806				2.2
LF9				passed on-sun			2.4
LF29				passed on-sun			2.6
LF28			failed @ IR imaging				2.9
LF4						IR failed on sun	3.5
LF3			IR failed I ramp @3.4A				3.6
LF15					shorted at N=1303		3.6
LF7			failed @ IR imaging				3.8
LF19					shorted at N=1262		4
LF8				IR failed on sun			4.4
LF17					IR failed I ramp @ 3.4A		4.4
LF10					IR ramp failed on sun		4.5
LF21		IR failed I ramp @3.4A					5.4
LF25			IR failed I ramp @3.6A				5.9

IR imaging and shorted samples represent lower bounds to their crack area %

thermal cycling

Summary of Results: sorted for increasing crack damage





conclusions

- 3 A current application for thermal cycling is benign to a healthy die-attach
- A corner crack ~3 area% of the cell is required to precipitate a representative failure.
- Die-attach damage severe enough to cause an on-sun failure is similarly detected via power cycling and the 4 A current ramp.