Metal Buss Tape Reliability

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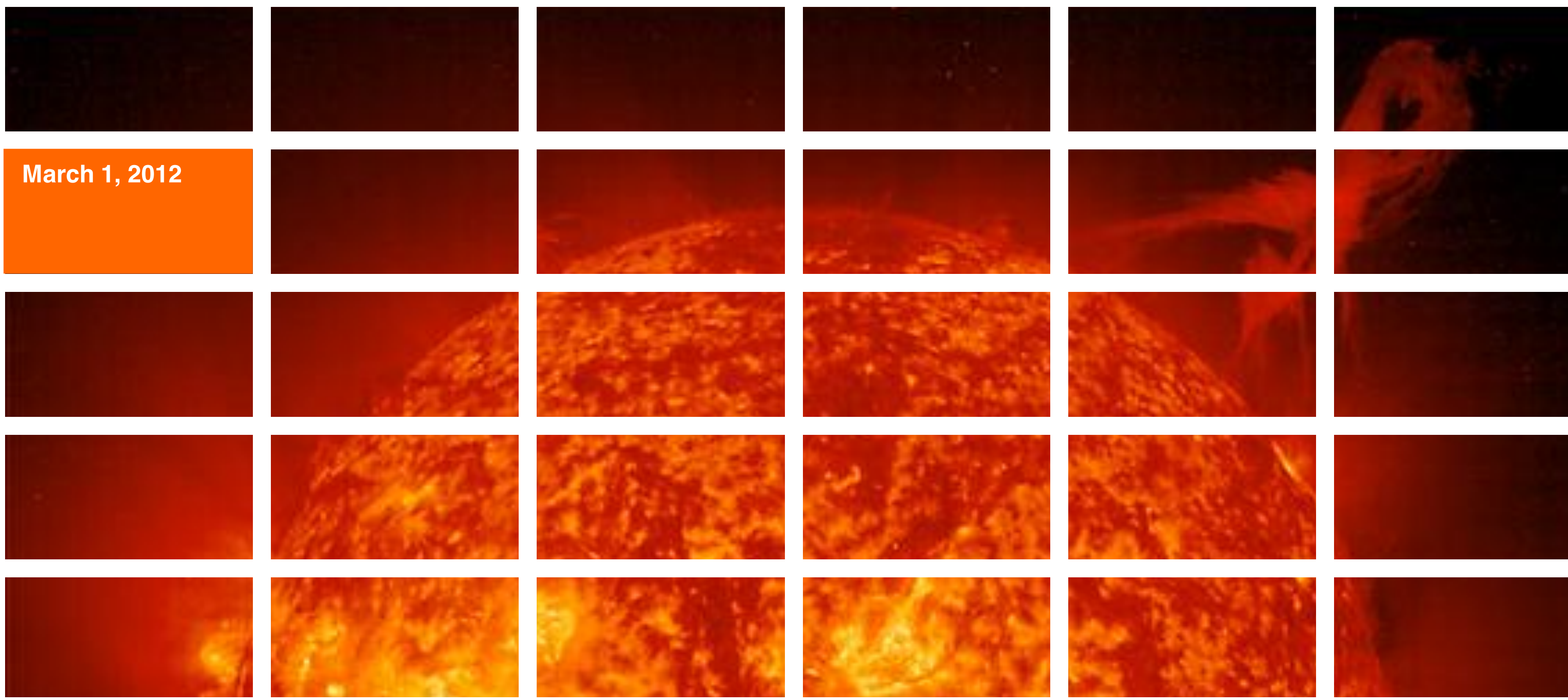


March 1, 2012

Why am I here?

Wisdom

Experience

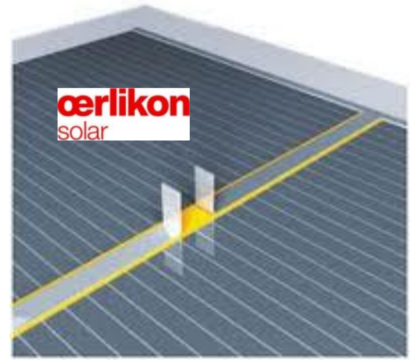
Failures

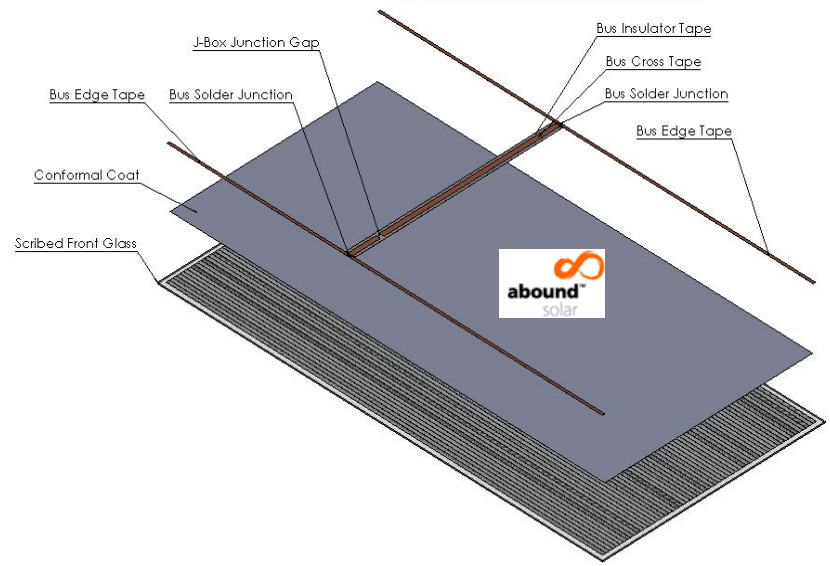
"There are no failures – just experiences and your reactions to them"

-Tom Krause

What exactly are metal buss tapes?

- Typically used for interconnect within a thin-film module to route generated power to the junction box.
- Most were derived from EMI shielding tape products and have evolved over time to meet the durability needs of PV modules





Buss Tape Technologies

Possibilities

- Metal foil with pressure-sensitive adhesive (PSA)
- Metal foil with epoxy adhesive
- Metal foil with ultrasonic soldering / resistive welding
- Metal foil with no adhesive (contract force alone)
- Others…

Embossed

Smooth

Variations

- Embossed vs. smooth
- Conductive vs. non-conductive adhesive
  - Make up and size distribution of conductive filler particles
  - Inclusion of carbon
  - Balance between adhesive and filler – conduction vs. adhesion
- Foil metallurgy
- Width and thickness
- Adhesive properties over temperature

Possible Reliability / Quality Concerns

Contact resistance shift (Rs)…worst case ‘dead open’

- Joint failure
- Loss of adequate tape adhesion
- Arcing / fusing of conduction points

Current carrying capacity (ampacity)

- Tape itself
- Tape-to-back metal
- Tape-to-tape joint

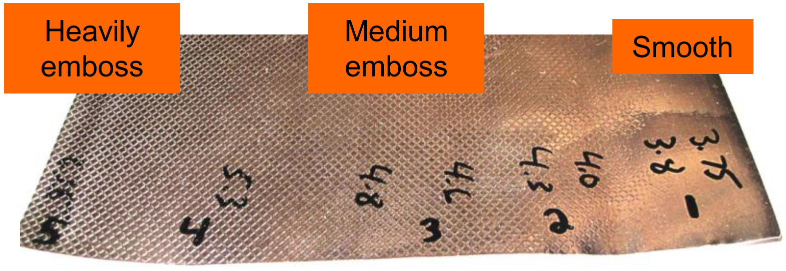
Arcing between tapes at junction box (spacings)

Shorting out adjacent cells (loss of power)

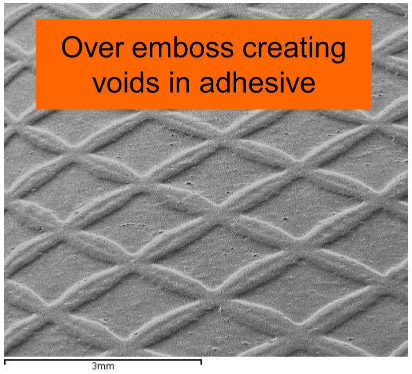
Metallurgical compatibility (galvanic corrosion)

Material CTE mismatches (Coefficient of Thermal Expansion)

Process Variability



- Roller pressure
- Roller durometer
- Roller wear out
- Speed of tape application
- Adhesive wetting
- Embossing depth control
- Conductive filler particle size & distribution
- Uniformity of conductive filler particles in adhesive
- Ability of tape vendors to monitor quality factors important for PV durability
- Slitting quality (coining, slitting tool wear, adhesive contamination, liners, etc)
- Tape batch variations and ability to detect good vs. bad (i.e. quality controls)
- Adhesive voids (i.e. trapped air pockets)
- Cleanliness of surface in contact with tape
- Topology of surface in contact with tape



And the worst…variability you don't know that you don't know about (ignorance is not bliss!)

Catastrophic ~~failures~~ experiences and your reactions to them

Buss damage along length of collector buss

Buss damage as seen from the backside of the module

Poor solder joint wetting

T-Joint failures

Film damage at burned conduction points

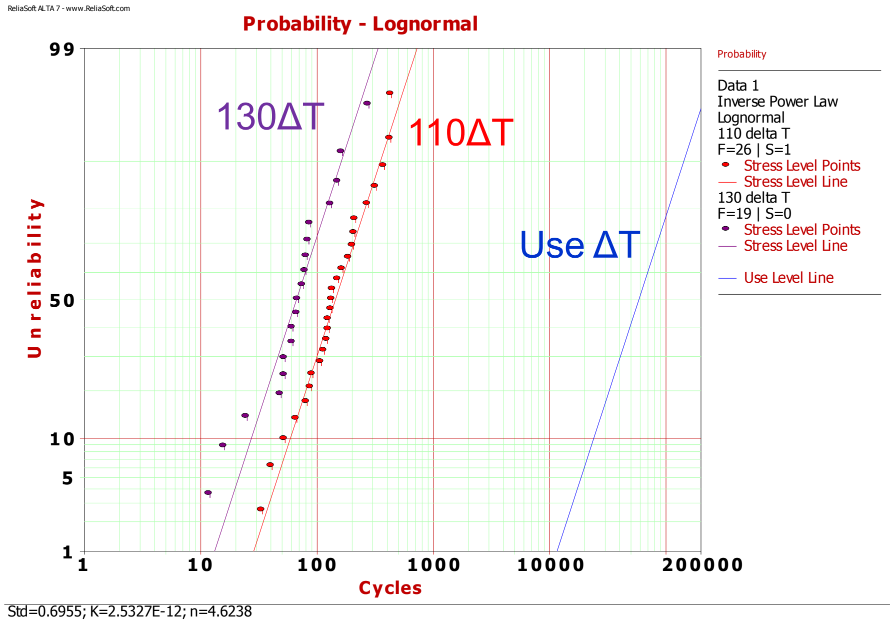
How best to accelerate buss tape failure mechanisms?

Stress Test	Catch Buss Failure Mechanism?	Reason
Temperature Cycling Test: UL1703, 35 (-40C to +90C, 200 cycles, small fwd bias current to assure continuity during cycle)	Occasionally	Failure mechanism requires both thermal fatigue and ***high current flow*** during cycles
High Temperature Bake (90C, 1000 hours, with and without high fwd bias current)	No	Failure mechanism requires both ***thermal fatigue*** and high current flow
Reverse Current Overload: UL1703, 28 (Fwd bias at 130% of fuse rating, 1 hour)	Occasionally	Failure mechanism requires ***thermal fatigue***. Much higher current flow (>200-500% of Isc) and longer stress duration increase chances of detecting failure mechanism. Hard to correlate to product lifetimes.
Damp Heat: IEC61646, 10.13 (85C, 85% R.H., 1000 hours, unbiased)	No	Failure mechanism requires both ***thermal fatigue*** and ***high current flow***
Humidity Freeze: UL1703, 36 (-40C to +85C/85%R.H., 10 cycles, small fwd bias current to assure continuity during cycle)	No	Failure mechanism requires both thermal fatigue and ***high current flow*** during cycles. Ten cycles is insufficient to provide enough thermal fatigue.
High Current Stress Temperature Cycling (-40C to +90C, test to failure, high fwd bias current, >2x-4x Isc)	Yes	Failure mechanism requires both **thermal fatigue** and ***high current flow*** during cycles. Must test to failure in order to get to tape wear-out.

Existing UL/IEC test methods are often insufficient to catch buss tape durability failure mechanisms

Temperature Cycle with varied ΔT, constant DC current

Looking at effects of two different ΔT stress levels

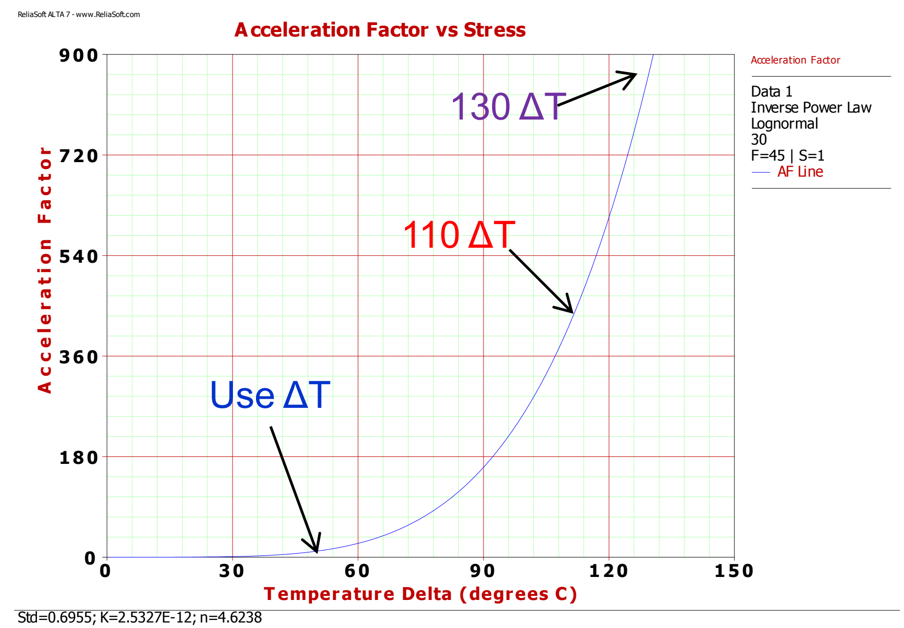


Buss Tape Details:

- Conductive adhesive
- High temperature rated adhesive
- UL Listing for PV

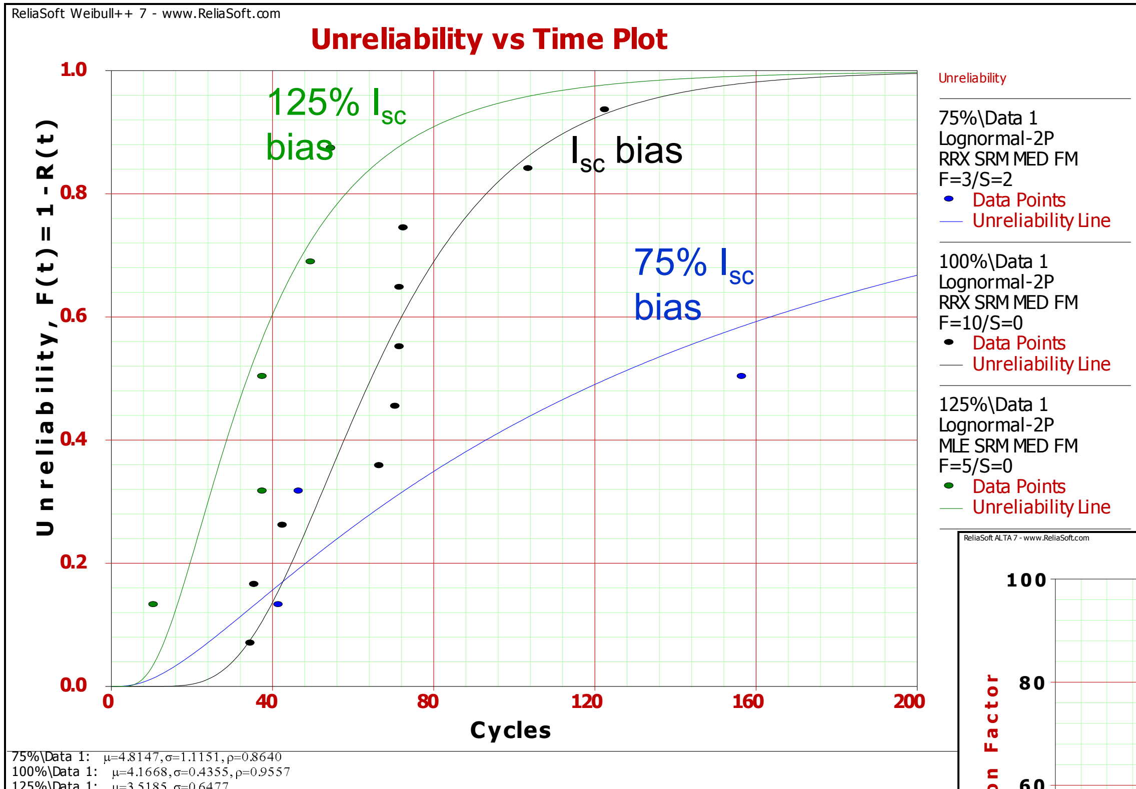
Observations:

- Thermal fatigue (Δ T) is a significant accelerant for buss tape failure
- The use of two or more stress conditions allow for extrapolation to use conditions and hence projections on ability to meet warranty for different climatic geographies
- A third Δ T condition will improve use condition prediction accuracy and narrow confidence bounds

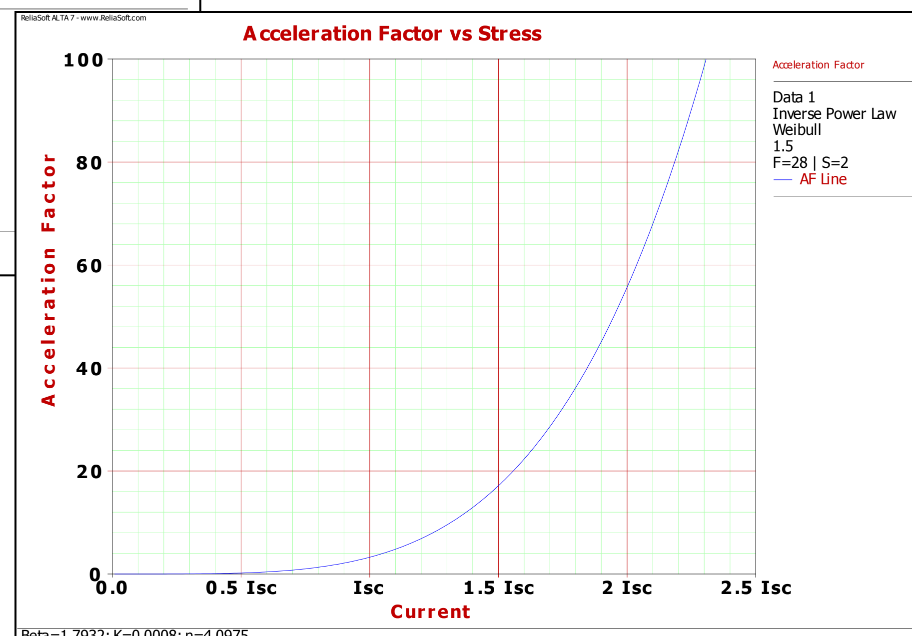


Temperature Cycle with constant ΔT, varied DC current

Looking at effects of three different current (irradiance) stress levels



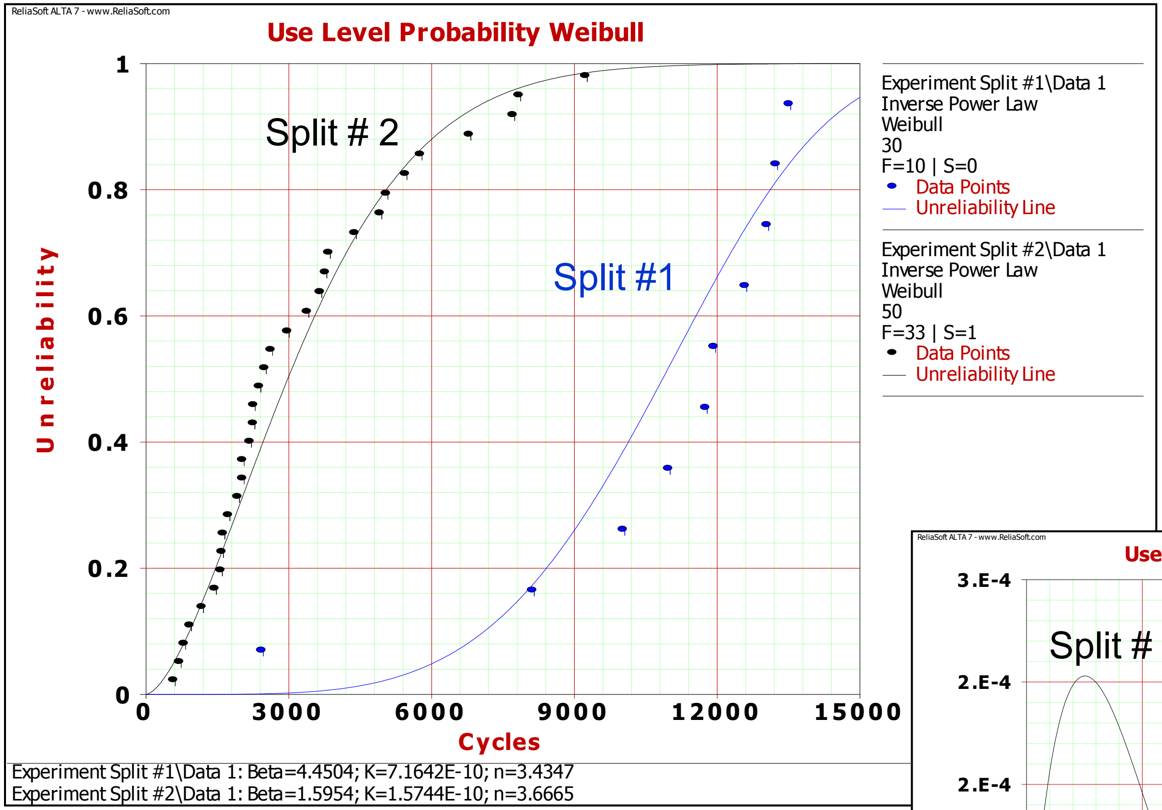
Buss Tape Details:
- Non-conductive adhesive
- "General purpose" temperature rating (i.e. not high temp rated)
- Former EMI tape with UL Listing for PV



Observations:
- Current (irradiance) is a significant accelerant for buss tape failure (ampacity)
- Tape UL Listing does <u>not</u> guarantee adequate PV reliability

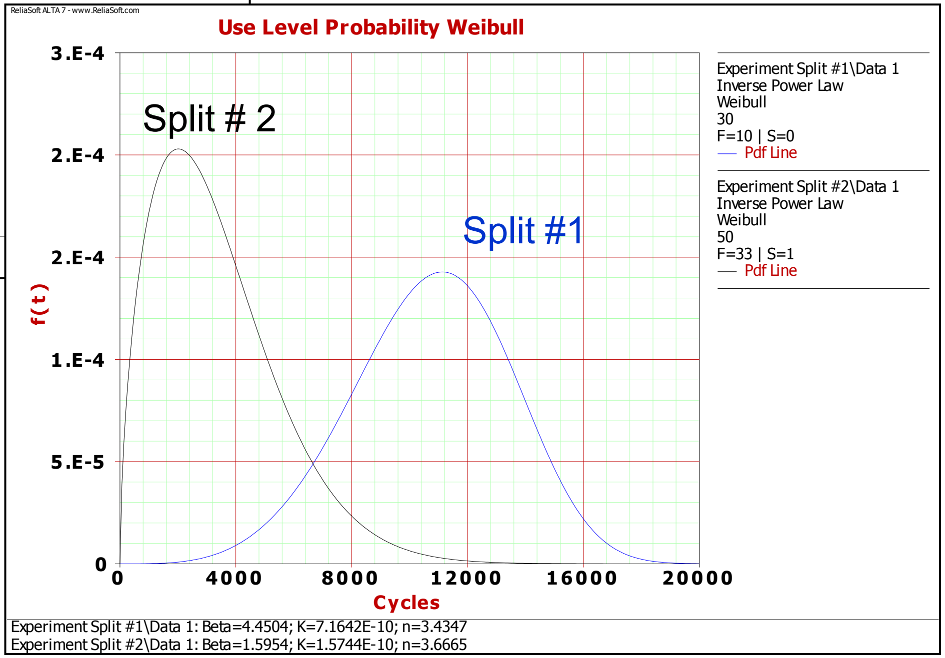
Temperature Cycle with varied ΔT, constant DC current

Looking at effects of two different manufacturing process parameters



Buss Tape Details:

- Conductive adhesive
- High temperature rated adhesive
- UL Listing for PV



Observations:

- Tape reliability can be significantly modulated with processing parameters / variability

Control your variability & optimize your process

Quantifying ΔT Cycle Counts from Weather Data

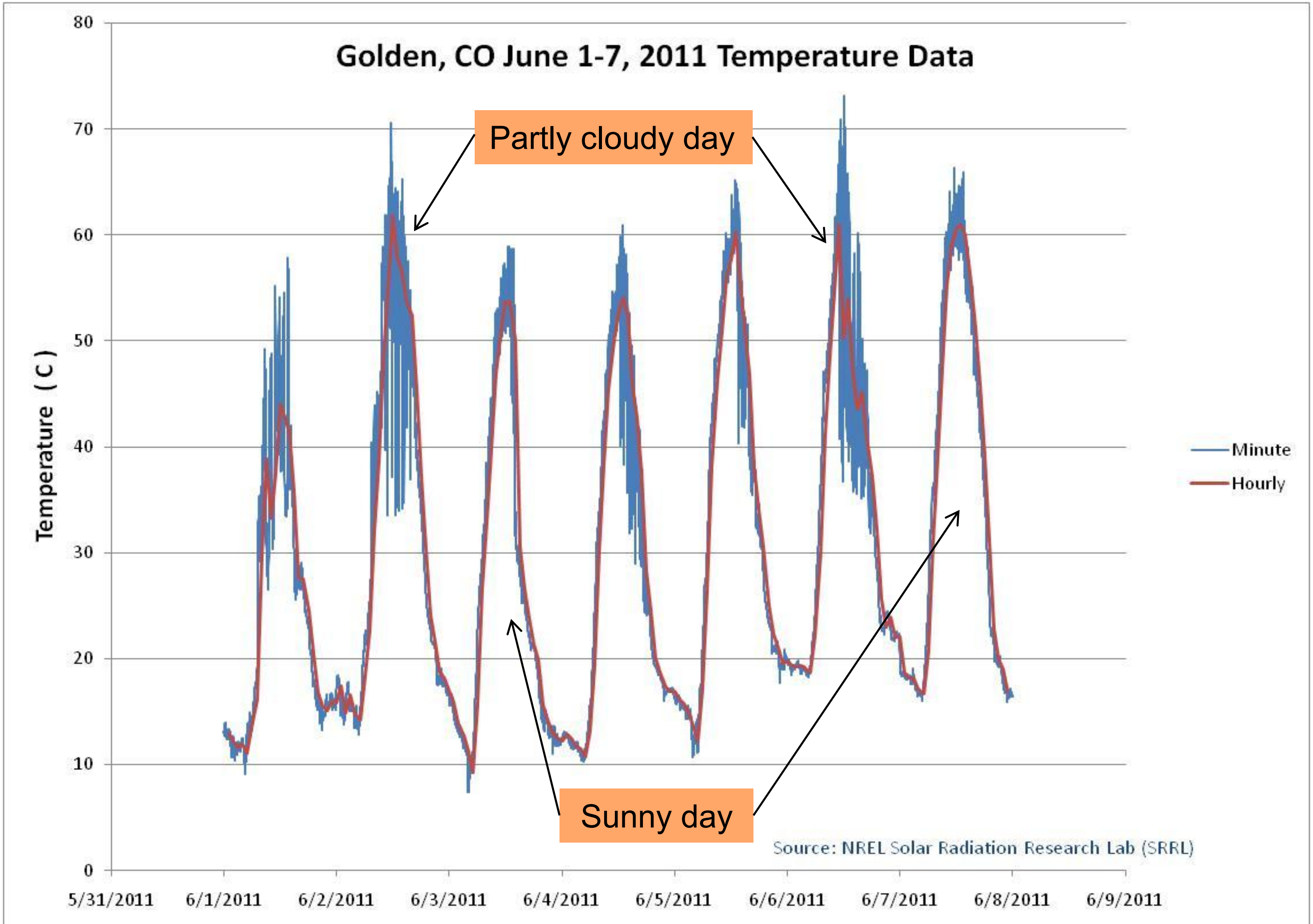
- Need to characterize and establish a Cell Temperature Model for your product based on readily available weather measurements such as ambient temperature, wind speed and irradiance [1, 2]

- Sampling rates of weather data can have a big influence on cycle counts, particularly on partly cloudy days. [3] *This is often an issue with publically available weather data, which tends to average raw data or record measurements too infrequently (ex. hourly)*

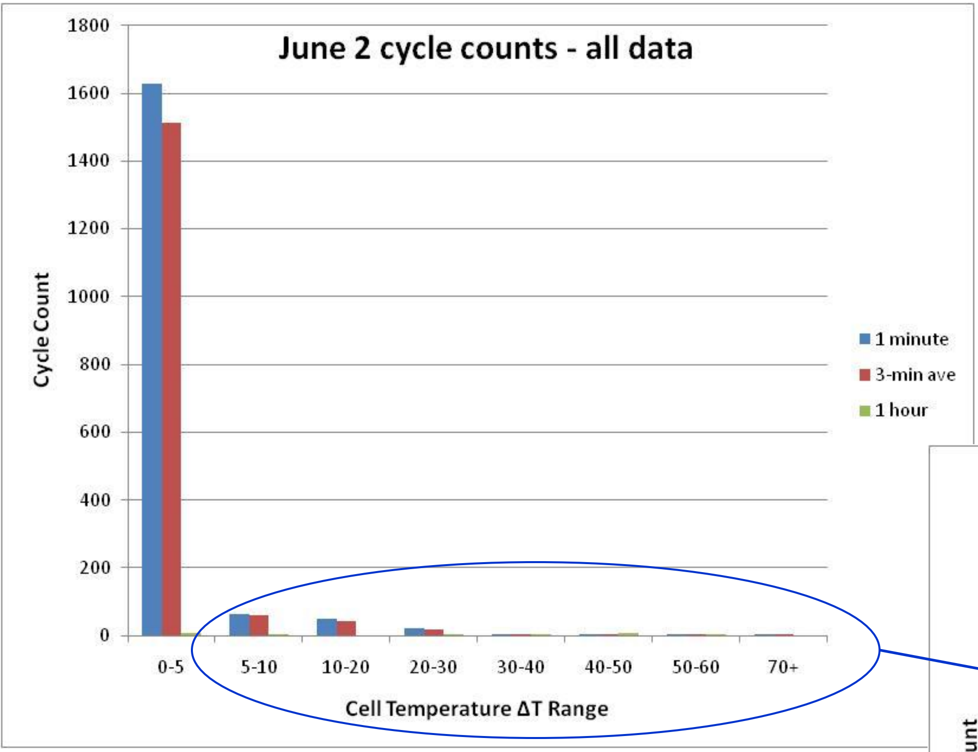
- Need to select a cycle counting algorithm[3,4] (ex. Rainflow or Peak & Valley) and means to process weather data into temp cycle counts such as StoFlo™[5]

- Seasonality and geography are huge factors in the accumulation and magnitude of ΔT cycles[3]

Quantifying ΔT Cycle Counts from Weather Data

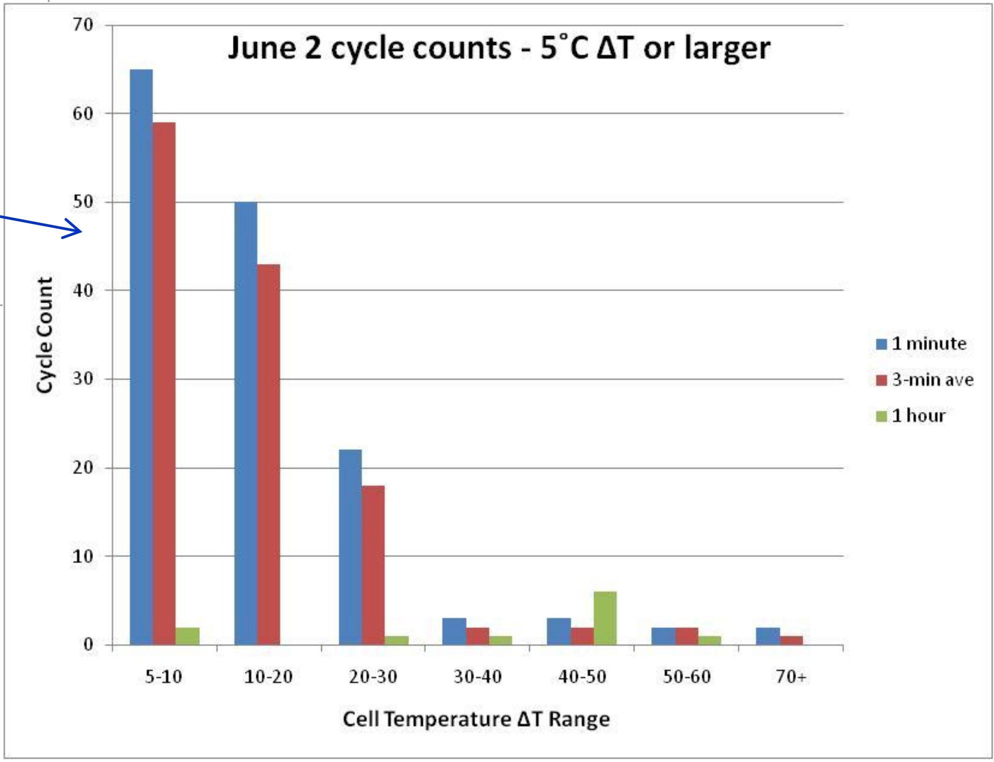


Histograms of Cycle Count data



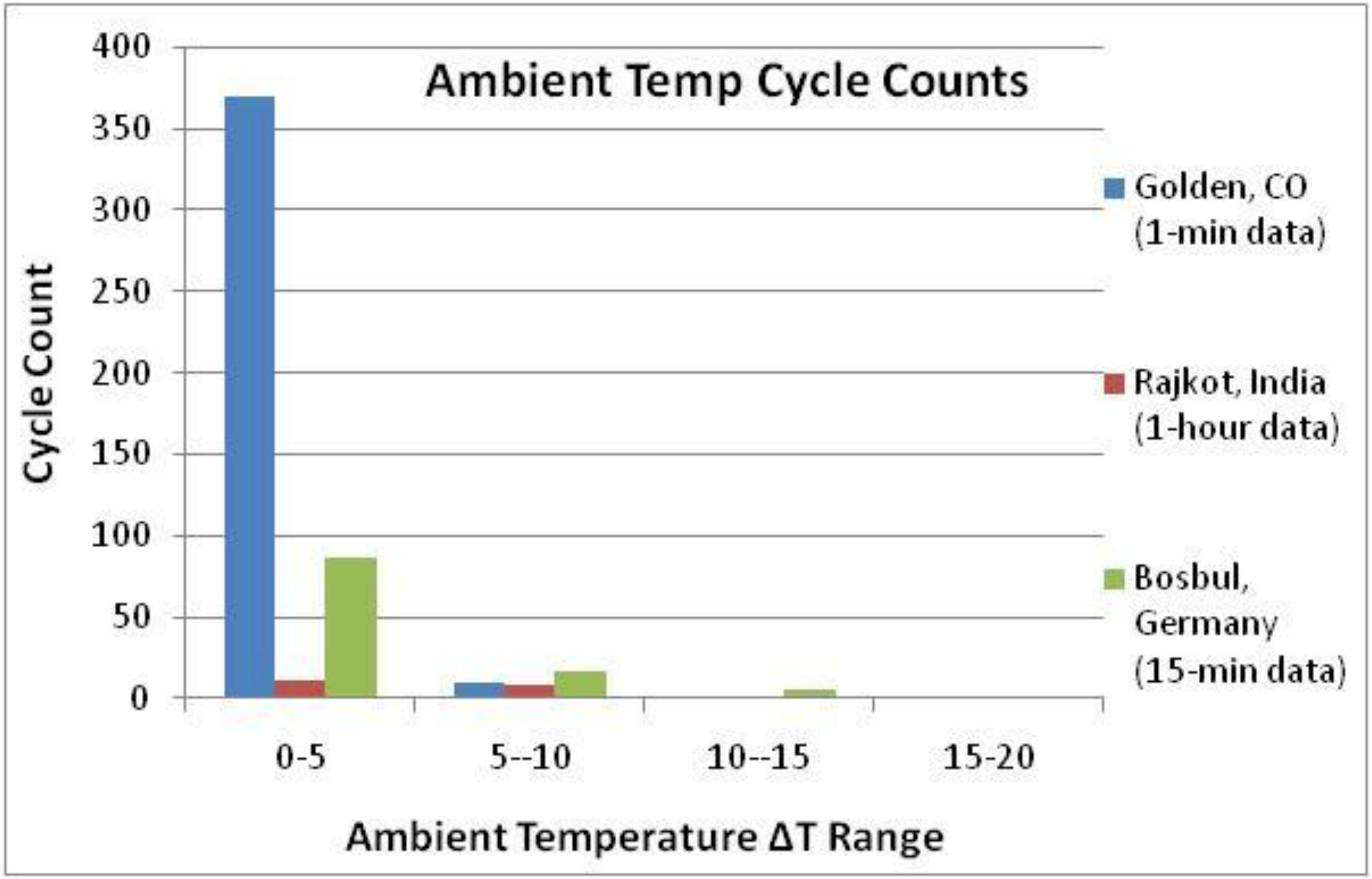
1 minute data		
Bin	*Frequency*	*Cum %*
5	1627	91.71%
10	65	95.38%
20	50	98.20%
30	22	99.44%
40	3	99.61%
50	3	99.77%
60	2	99.89%
70	2	100.00%

1 hour data		
Bin	*Frequency*	*Cum %*
5	9	45.00%
10	2	55.00%
20	0	55.00%
30	1	60.00%
40	1	65.00%
50	6	95.00%
60	1	100.00%
70	0	100.00%



Hourly data grossly underestimates the amount of thermal fatigue during partly cloudy day

Geography and measurement interval differences



- Cycle count depends largely on location[3]
- Readily available weather measurement data varies considerably
  - 1-hour interval weather data is very gross and inadequate to model predictions
  - 15-minute interval weather data is better, but not ideal
  - 1-minute interval weather data is best and recommended

Tying lab data to weather for field projections

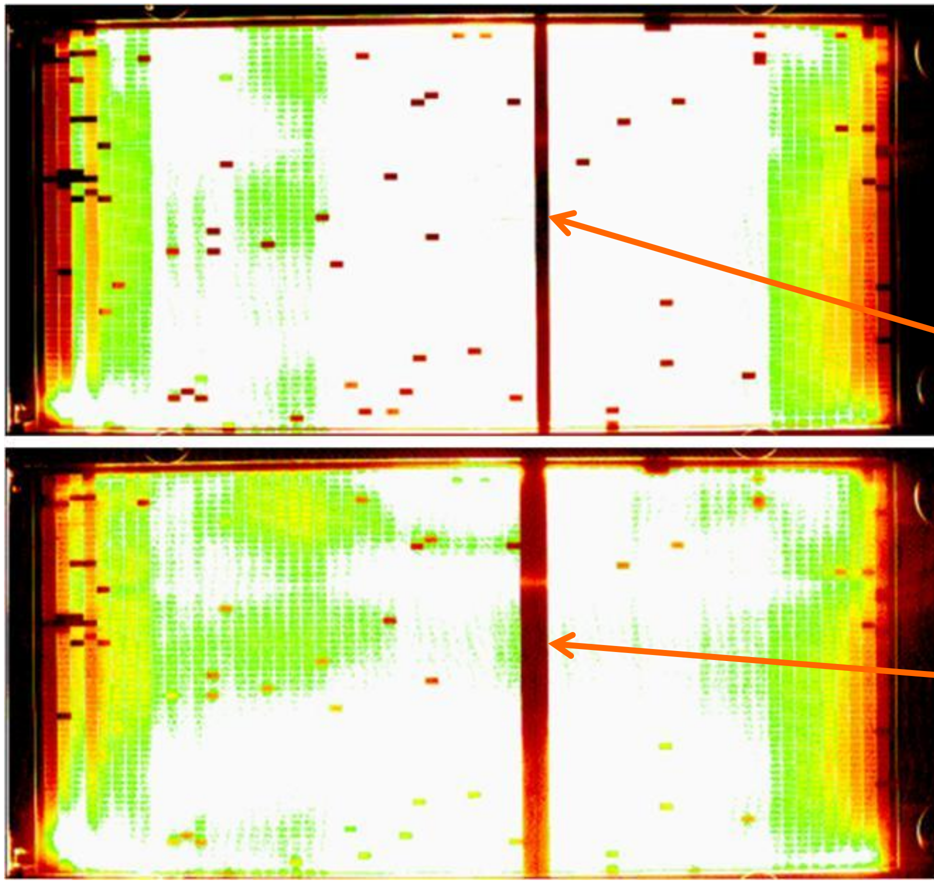
- Multiple condition stress test data and actual field failure data can be entered into an accelerated life test analysis tool such as ReliaSoft's ALTA®

- Data is used to find a best fit failure distribution curve
    - Data can include suspensions (i.e. modules that have survived some amount of time/stress – majority of field samples)
    - Temperature profiles can be fed into software as an input to account for different geographies, times of year, etc.
    - Monte Carlo analysis can be used to tighten confidence bounds when analysis sample sizes are limited
    - Time-to-failure, confidence intervals, failure mechanism activation energies, acceleration factors, and warranty information can be calculated at different geographies

Predictability

FA techniques – LBIC (Light Beam Induced Current)

LBIC used in conjunction with 2 cm lengths of perpendicular laser isolation



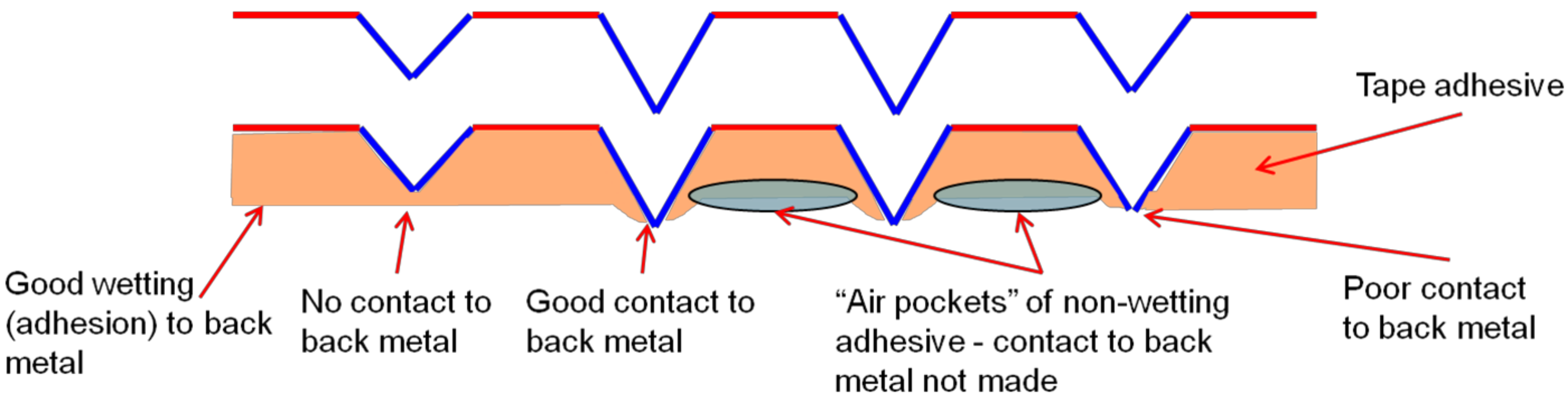
LBIC Description

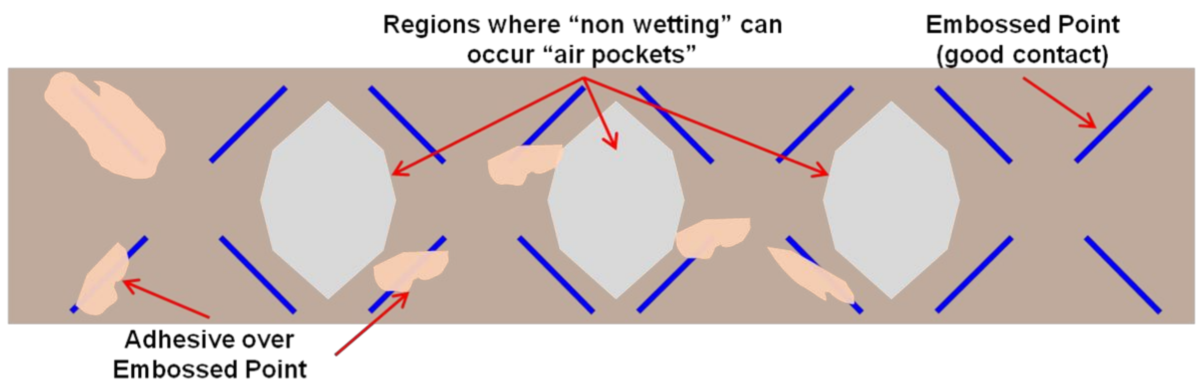
- Scanning of a light beam over a cell while measuring the resulting short-circuit current for each position.
- The collected current variations are correlated to laser locations resulting in a current map.

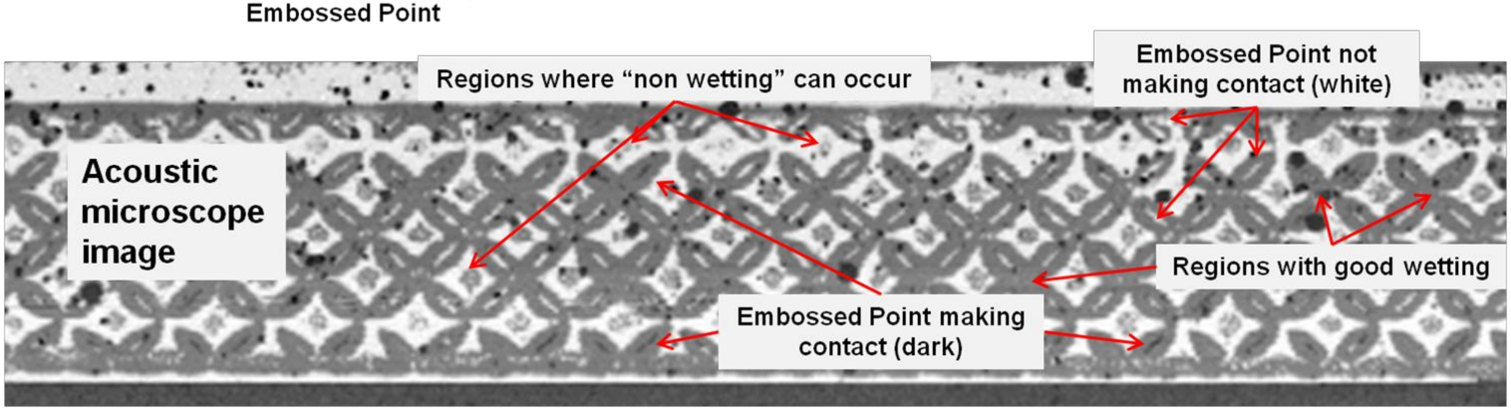
Dark vertical line shows location where a 2 cm length of the metal buss tape is not making contact with the back metal

After additional stress testing, another 2 cm length of metal buss tape has failed

FA Technique – Acoustic Analysis



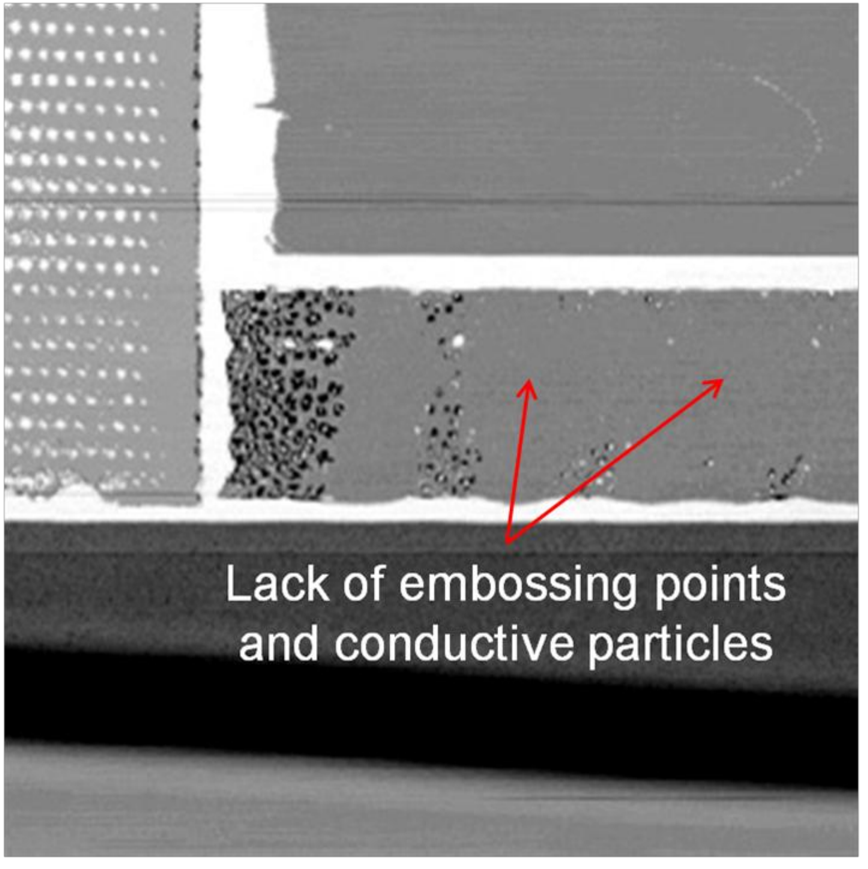


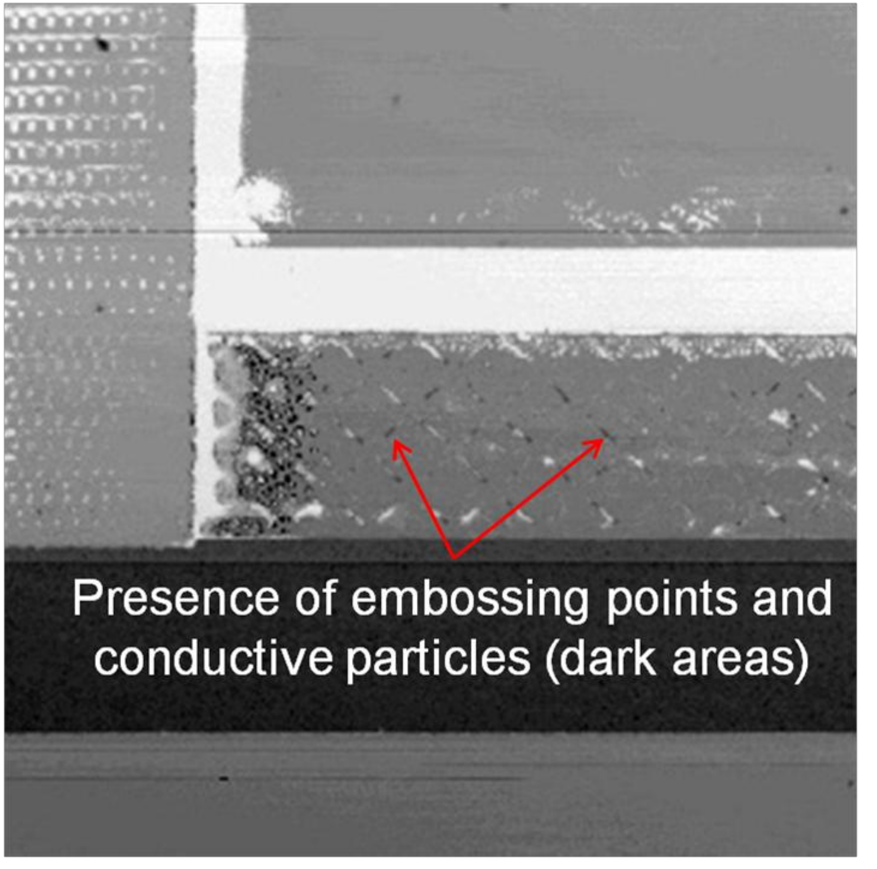


FA Technique – Acoustic Analysis (2)

Acoustic image of poor tape application that results in buss tape failure

Acoustic image of good tape application that results in reliable buss tape



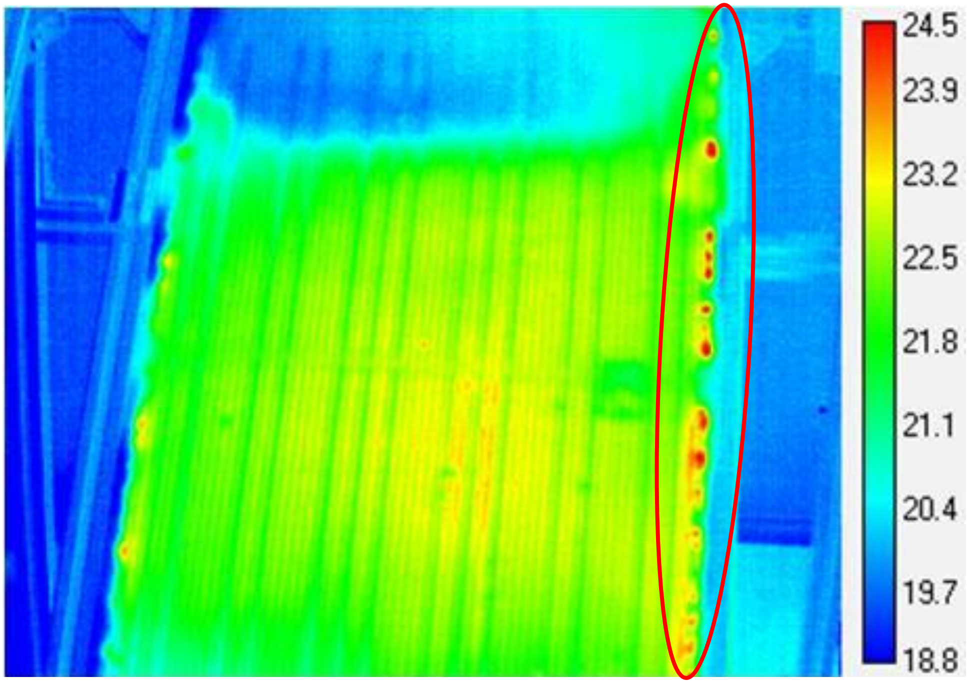


FA Technique - Thermography

- **Infrared (IR)** imaging is a technique that has been in existence for a long time.
  - Great at finding shunt related defects that have a high thermal emission
  - Cannot easily detect series related resistances due to uniform thermal heating
  - Technique is limited by spatial resolution and thermal diffusion due to integrating under full power over time

- **Lock-in Thermography (LIT)** synchronizes the excitation source (light, voltage, etc.) to the IR camera's data acquisition
  - Allows detection of subtle thermal responses beyond the noise floor limitations of the IR camera.
  - Mapping of the weaker shunting/series resistance defects are enabled because of the better detection limits.
  - A much lower excitation is needed to acquire the thermal response on a module, this prevents over current/voltage stressing of the module which will result in damage.

FA Technique - Infrared (IR) camera



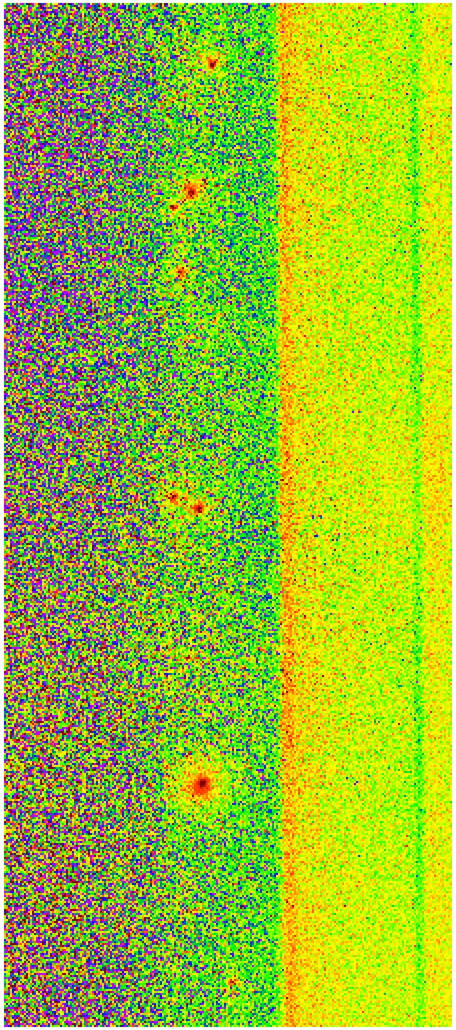
IR image showing poor ohmic contact areas along metal buss tape prior to failure

IR spatial resolution and thermal diffusion usually limit its usefulness for buss tape analysis

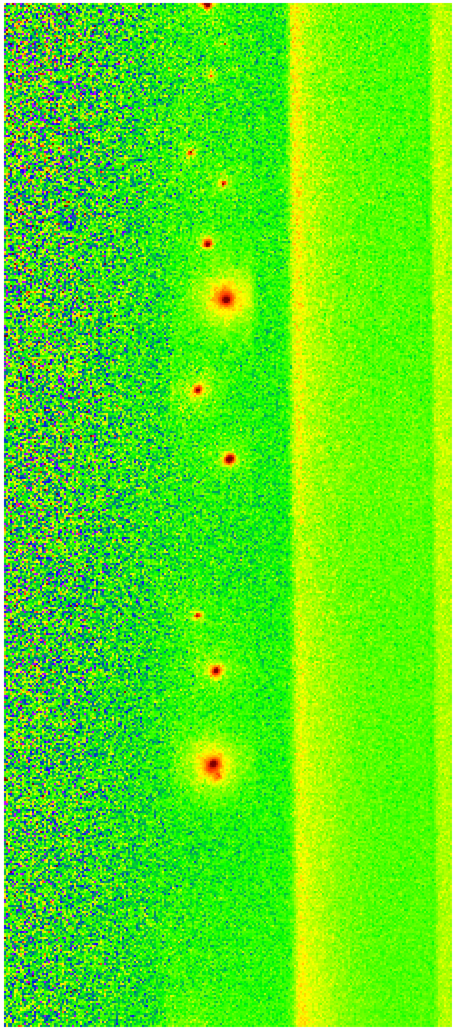
FA Technique – Lock-in Thermography

Inadequate buss tape

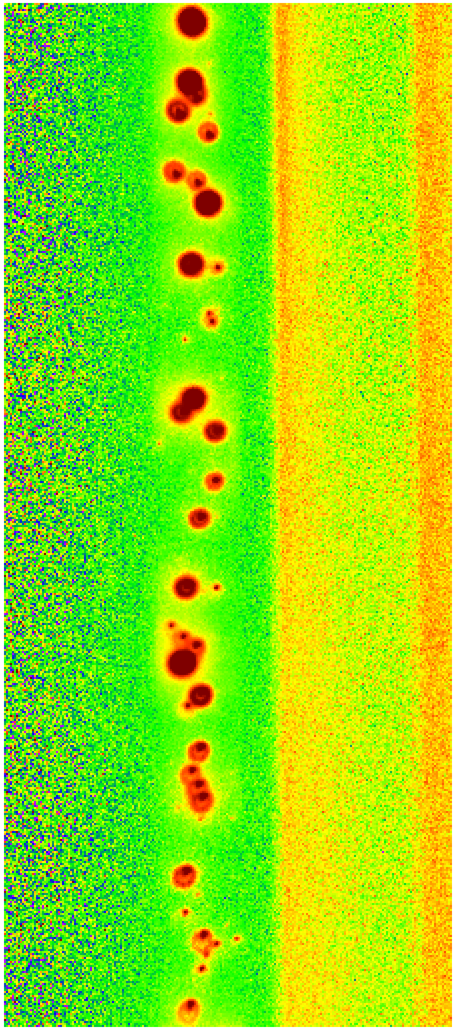
Time Zero



Post 24 Cycles



Post 74 Cycles



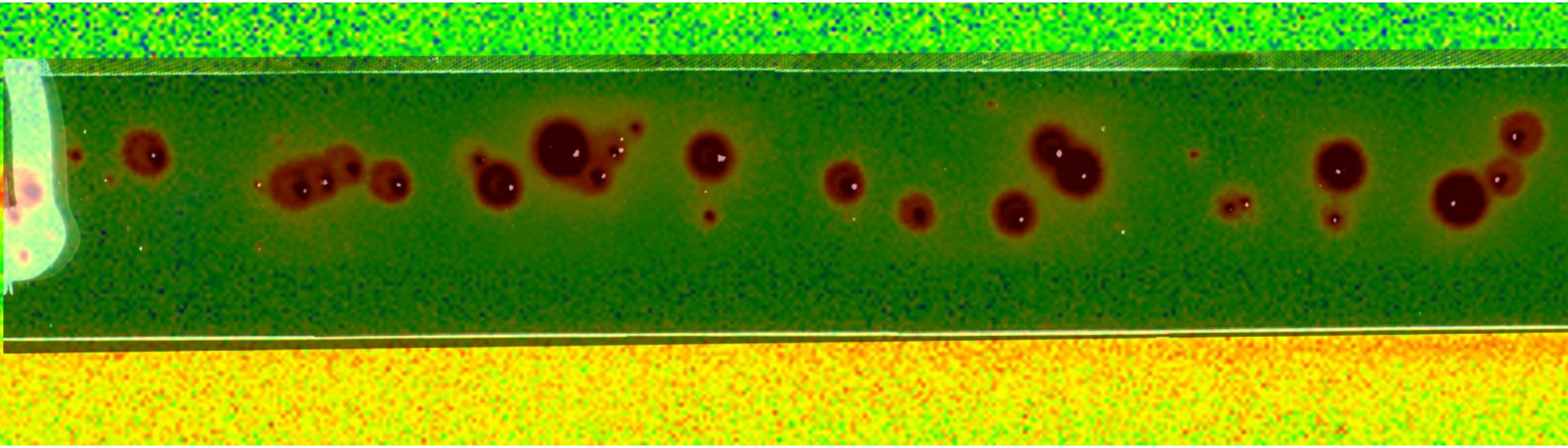
Optical photo of film surface

FA Technique – Lock-in Thermography (2)

Inadequate buss tape

Optical image was overlaid onto the LIT image

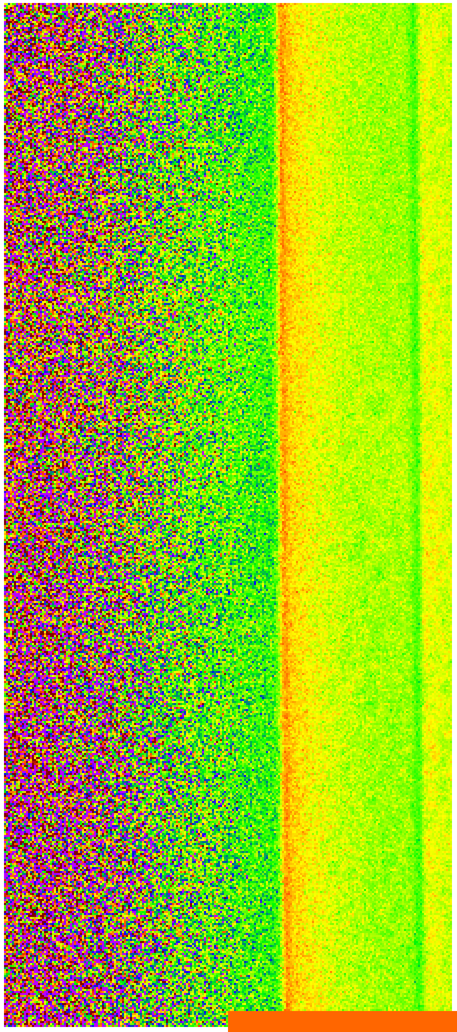
High correlation of visible burned film and the lock-in thermal response.



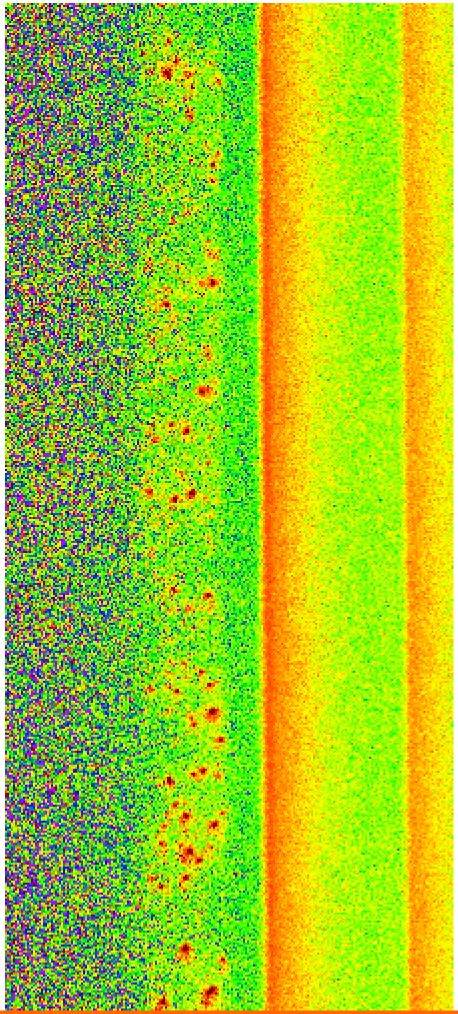
FA Technique – Lock-in Thermography (3)

Robust buss tape

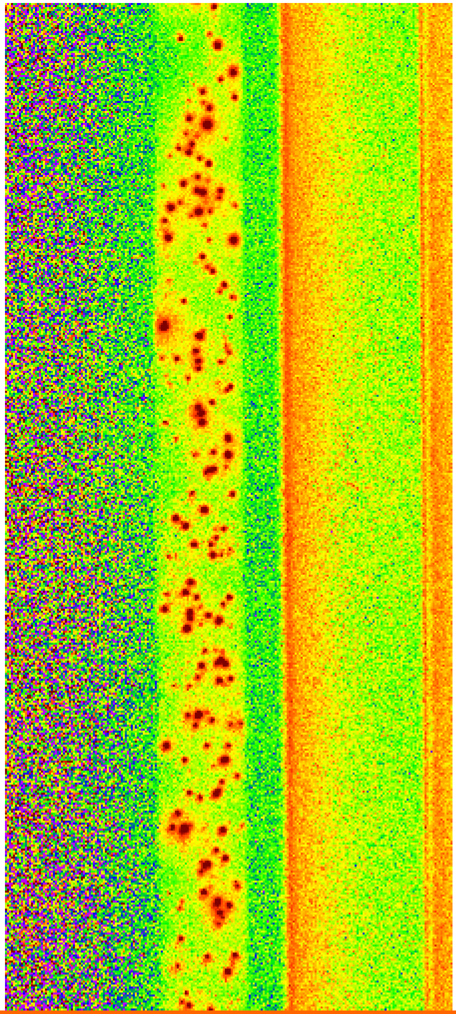
Time zero



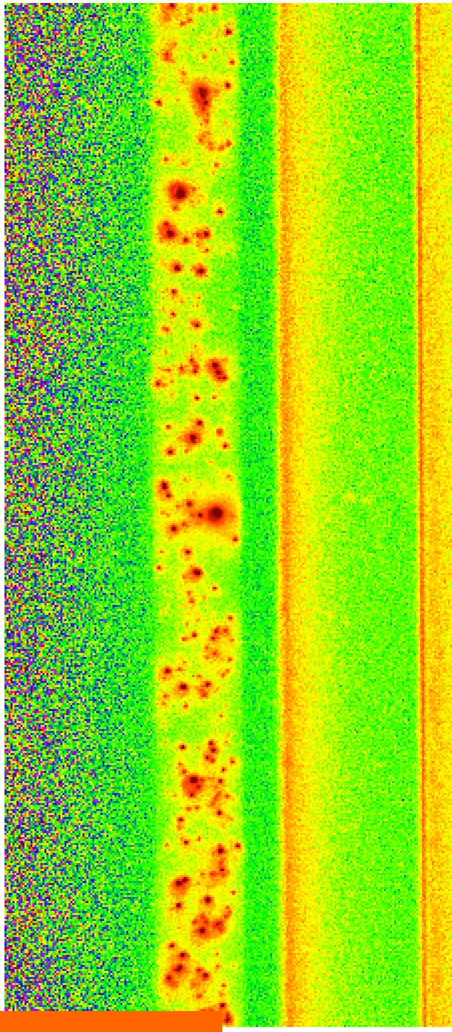
Post 104 Cycles



Post 275 Cycles



Post 507 Cycles



Module shows no signs of film damage or degraded performance

I hope my "wisdom" has convinced you that failures are not only good, but absolutely necessary for understanding your product

"Success is never final; failure is never fatal"

"I didn't fail the test, I just found 100 ways to do it wrong" – Benjamin Franklin

"Try and fail, but don't fail to try" – Dave Checkett

"The greatest barrier to success is the fear of failure" -Sven Goran Eriksson

"Failure is the tuition you pay for success" -Walter Brunell

"There are no secrets to success. It is the result of preparation, hard work, and learning from failure" -Colin Powell

References

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5. D. Storera, StoFlo™ Rainflow Cycle Counting Excel Template with Macros, http://stotera.com/stoflo/