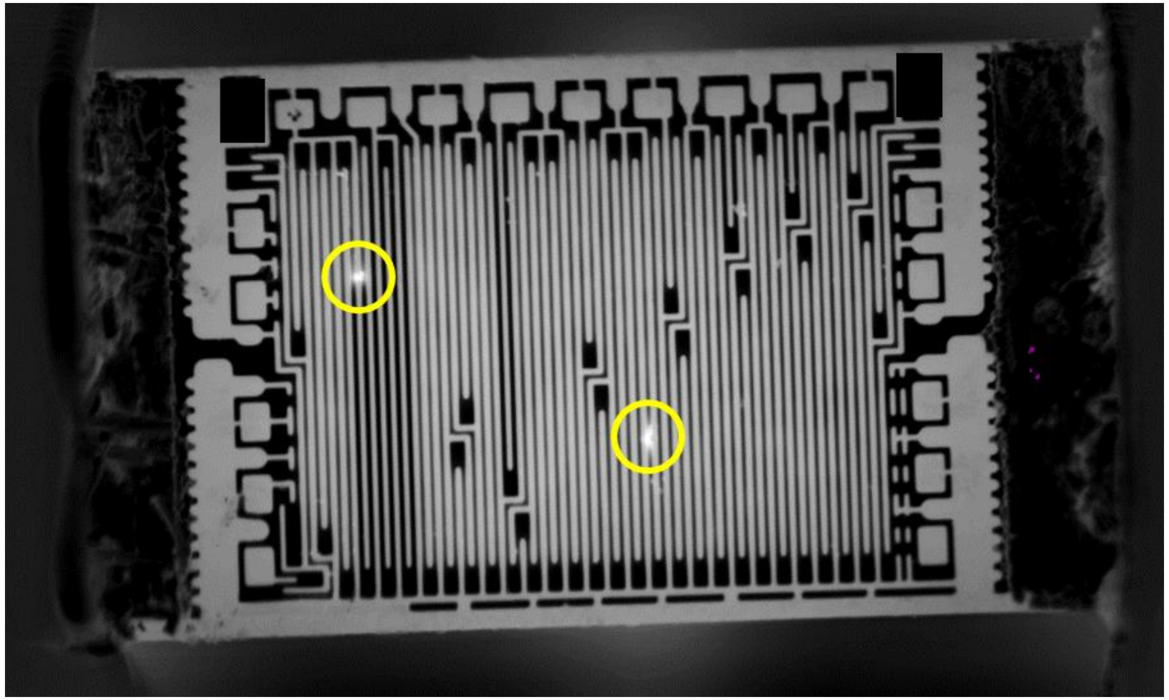
A Screening Method Using Pulsed-Power Combined with Infrared Imaging to Detect Pattern Defects in Bulk Metal Foil or Thin Film Resistors



Jay Brusse

ASRC AS&D at NASA Goddard Space Flight Center

Lyudmyla Panashchenko

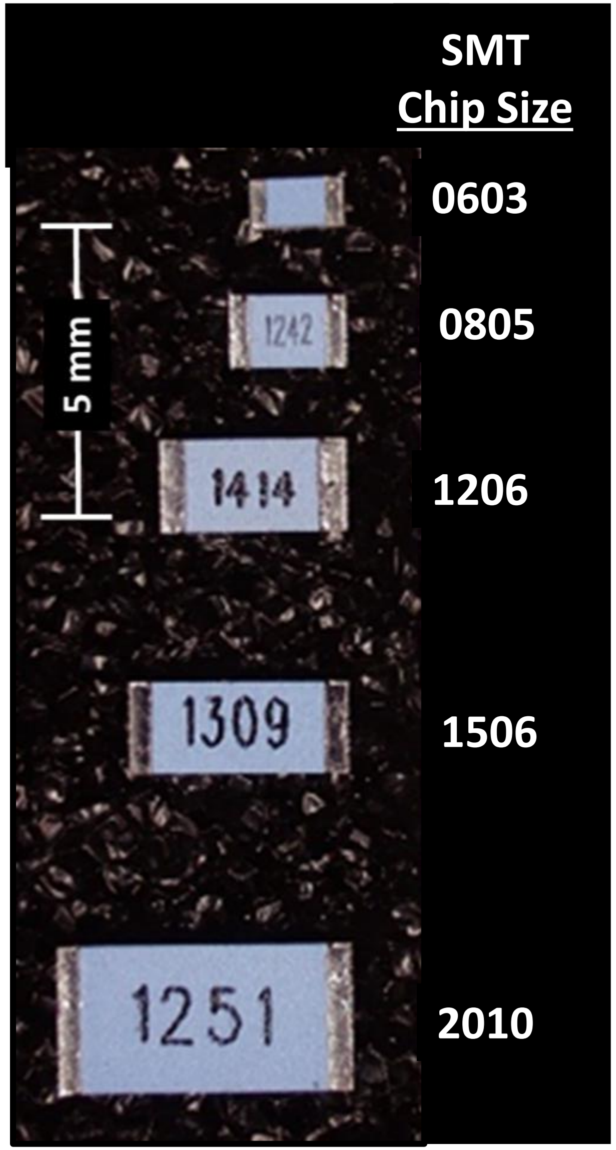
NASA Goddard Space Flight Center

Acronyms & Abbreviations

Al-N	Aluminum Nitride
DPA	Destructive Physical Analysis
FA	Failure Analysis
InSb	Indium Antimonide
NASA	National Aeronautics and Space Administration
NEPP	NASA Electronic Parts & Packaging (NEPP) Program
NiCr	Nichrome
ppm	Parts Per Million
PWB	Printed Wiring Board
SEM	Scanning Electron Microscope
SMT	Surface Mount Technology
STOL	Short Time Over Load
TCR	Temperature Coefficient of Resistance

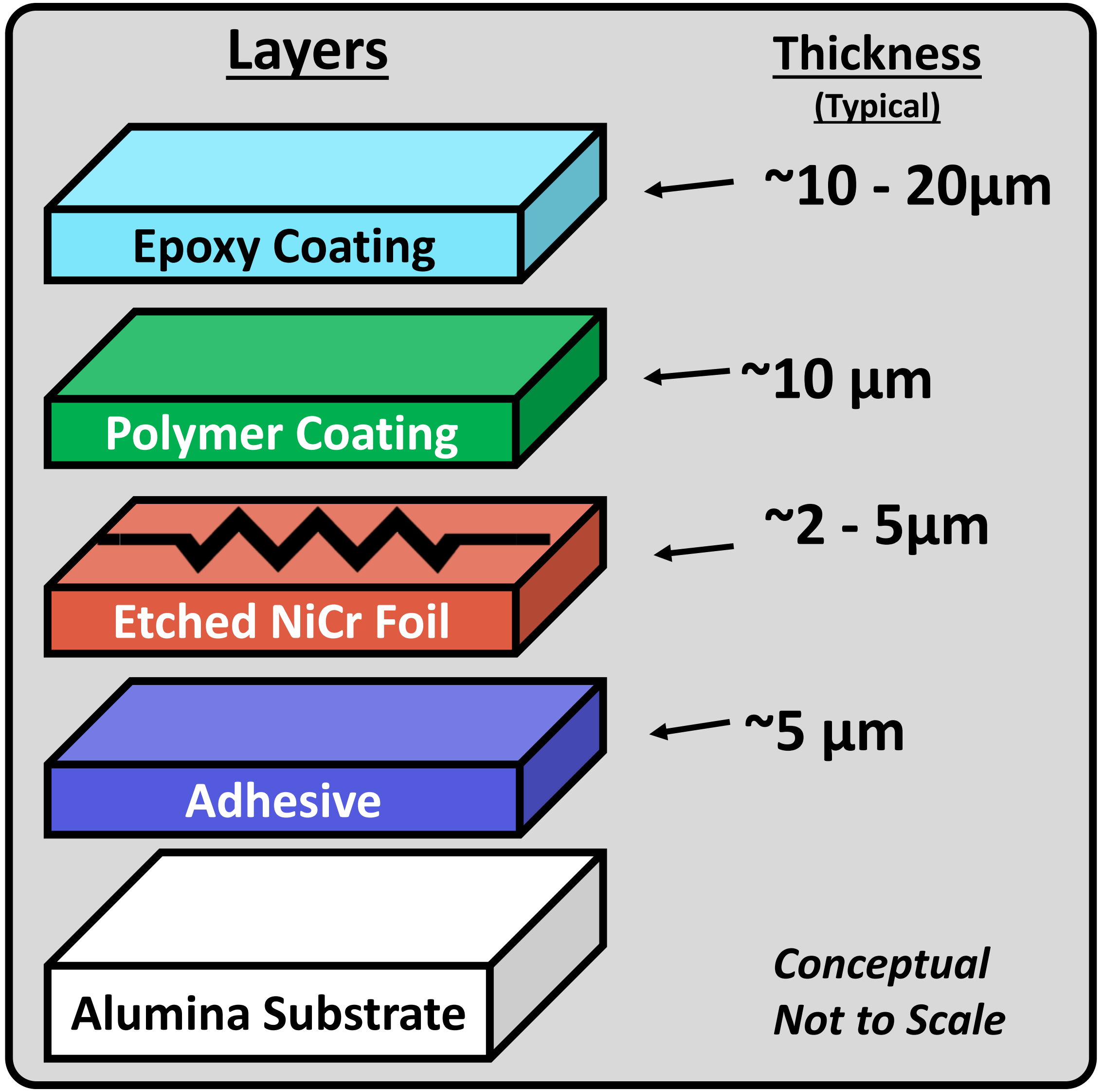
Foil Resistors Have Many Favorable Attributes

Attribute	
Package Configurations	Surface Mount Technology (SMT); Through Hole
Resistance Values	Custom Values; 5Ω to 125kΩ (standard SMT)
Resistance Tolerance	± 0.01% (± 100 ppm)
Temperature Coefficient of Resistance (TCR)	< ± 1 ppm/°C from -55°C to +125°C
Load Life Stability	± 0.03% (± 300ppm) after 2k hour life test @ 1x rated power @ 70°C



Basic Construction of a SMT Foil Resistor

- Resistor element is made from foil sheets of NiCr-based alloys
- Resistor gridline patterns are created by photolithography and electrochemical etching
- Resistor foil is adhesively-bonded to an alumina substrate
- Precise resistance values achieved by laser or mechanical cutting of combinations of “trim tabs” connected in parallel with resistor pattern segments of different values
- Various resistor termination options exist
- Polymeric and epoxy coatings protect the resistor element



Foil Resistor Gridline Patterns

$$R = \frac{\rho * L}{A}$$

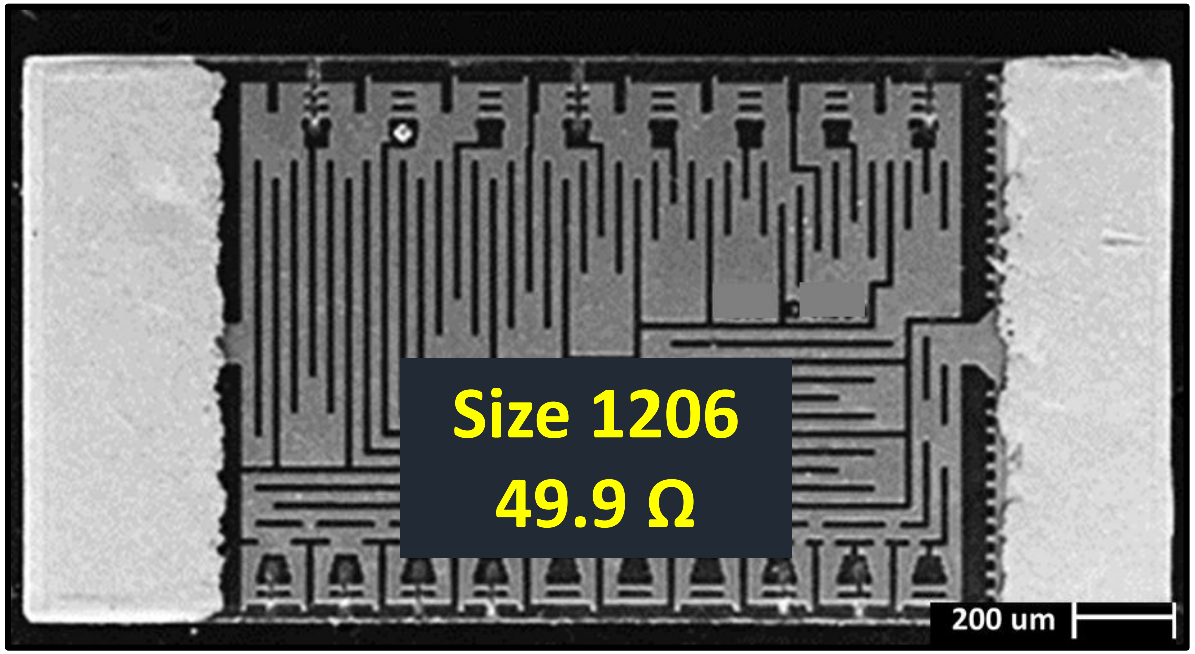
R = Resistance (Ω)
ρ = Resistivity of Foil
L = Length of Resistor Element
A = Cross Sectional Area of Gridline
*(i.e., thickness * width)*

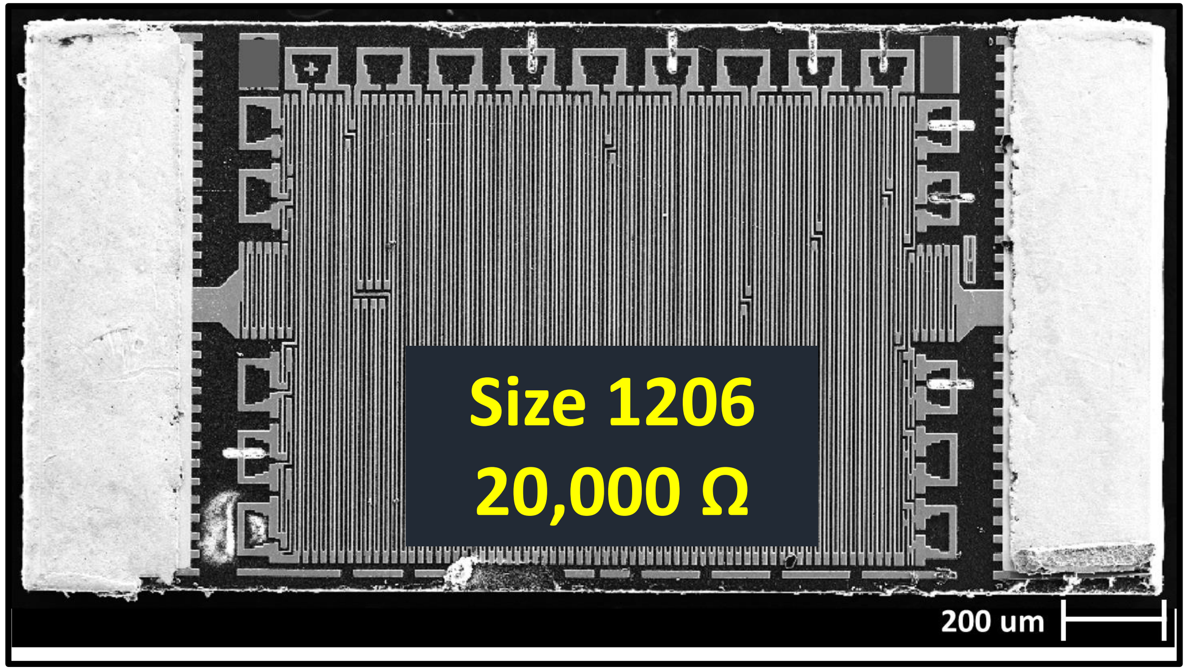
Low Resistance Values

1. *Wider Foil Gridlines (e.g.,~ > 10 µm)*
2. *Thicker Foil (e.g., ~ 5 µm)*
3. *Shorter Path Lengths*

High Resistance Values

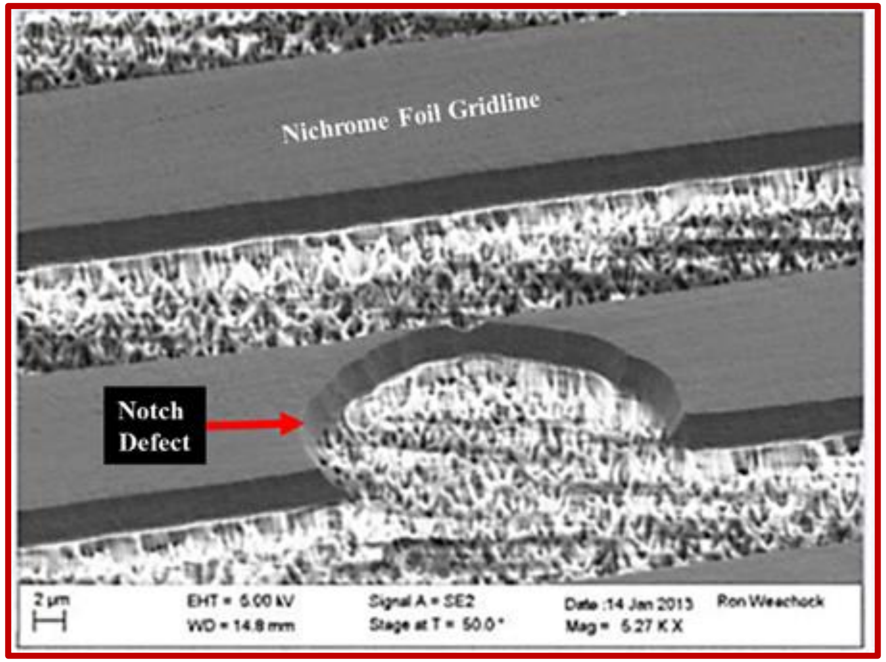
1. *Narrower Foil Gridlines (e.g.,~ < 10 µm)*
2. *Thinner Foil (e.g., ~ 2 µm)*
3. *Longer Path Lengths*



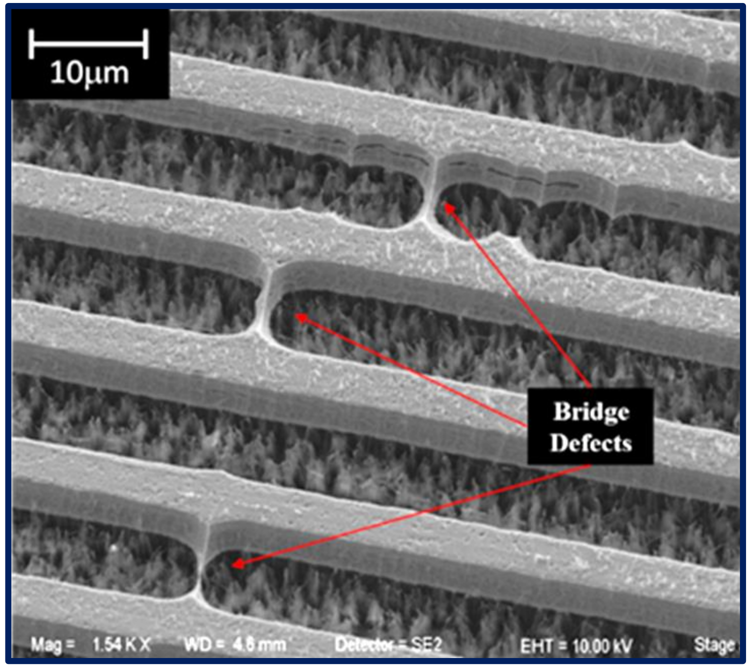


Foil Resistors Are Sometimes Produced with Localized Constriction Defects in the Gridline Pattern

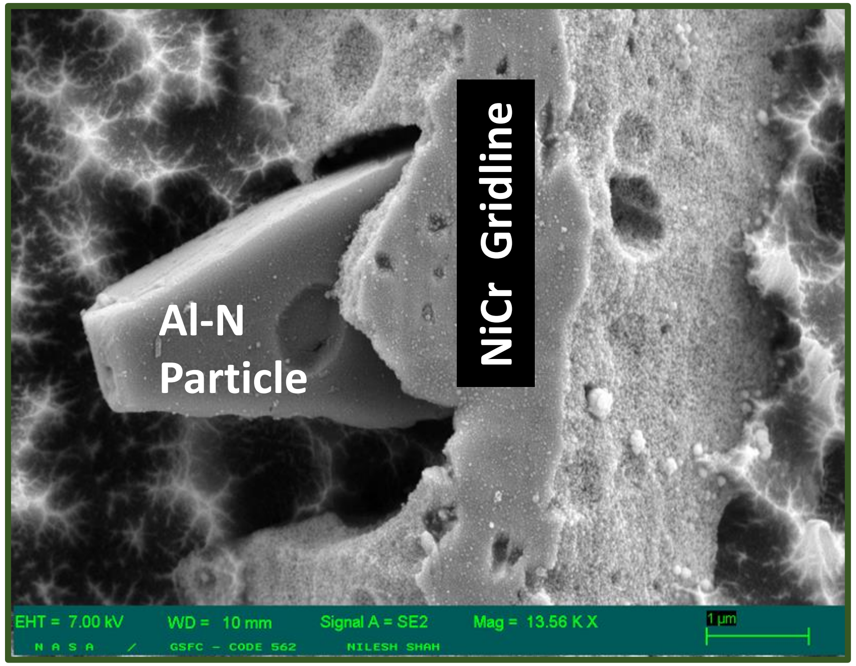
Notches



Bridges



Embedded Particles



1. Constriction defects contribute directly to the final resistance value (e.g., bridges provide parallel resistor pathway).
2. Constriction defects are at risk of breaking due to thermomechanical fatigue fracture <u>especially during power cycling</u>
    1. Constrictions carry higher current density and develop localized 'hot spots' due to Joule heating
    2. Hot spots produce locally greater expansion of the NiCr foil
3. *If a constriction defect fractures, then a positive resistance shift, including open circuit, will occur.*

Standard Screening Tests are Not 100% Effective at Detecting Constriction Defects

Despite Performing These Screening Tests,
Resistors with Significant Constriction Defects are Still Occasionally Received

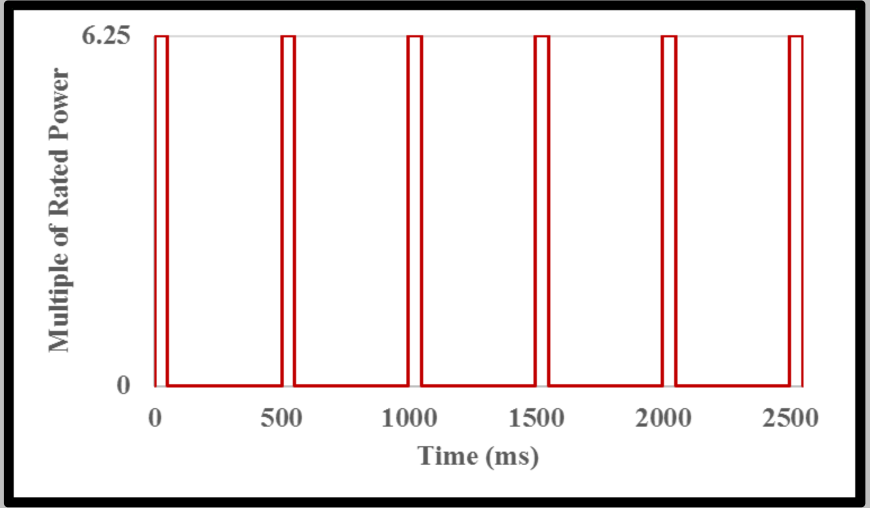
Test Method	Test Conditions	Rejection Criteria
Pre-Encapsulation Optical Microscopy	30x to 60x Magnification	Notches > 75% nominal line width Bridges < 10% smallest line width
Short Time Overload (STOL)	6.25x Rated Power For 5 Seconds	ΔR > 0.02%
Power Conditioning	1x to 1.5x Rated Power @ Max Operating Temp For 100 Hours	ΔR > 0.03%

Hot Spots! A New Screening Method to Detect Localized Constrictions

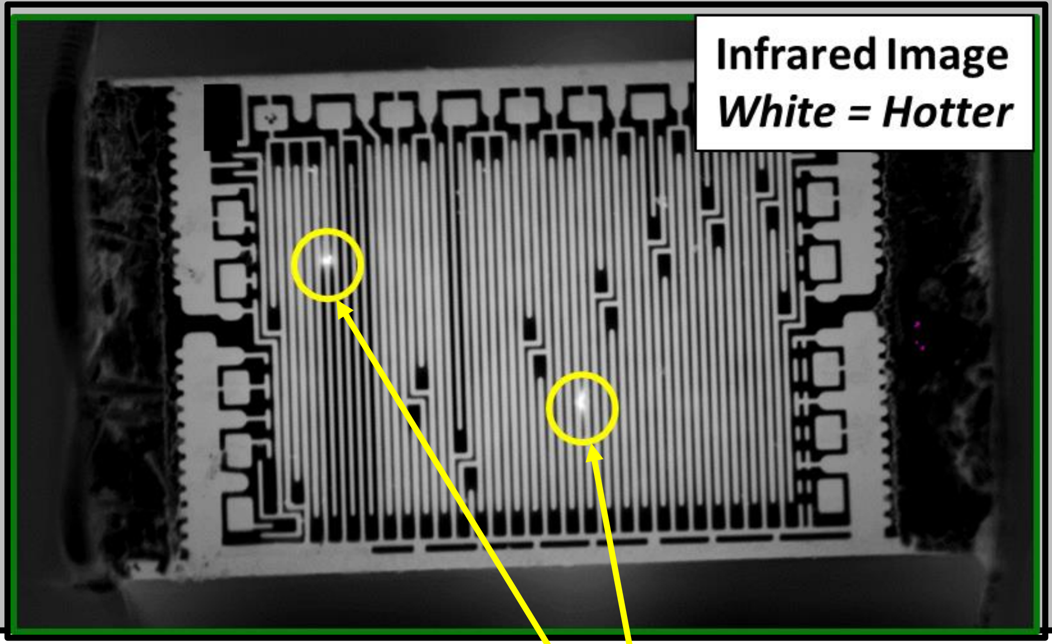
Pulsed-Power Combined with High Resolution Infrared Imaging

1. Apply pulsed-power to resistor

- **6.25x rated power ← *same as STOL***
- **50 ms, 10% duty cycle**
- **1 or more pulses**
- **These conditions confine heating to the localized constrictions**



2. Examine resistor with *high resolution infrared camera* (e.g. FLIR SC8300)



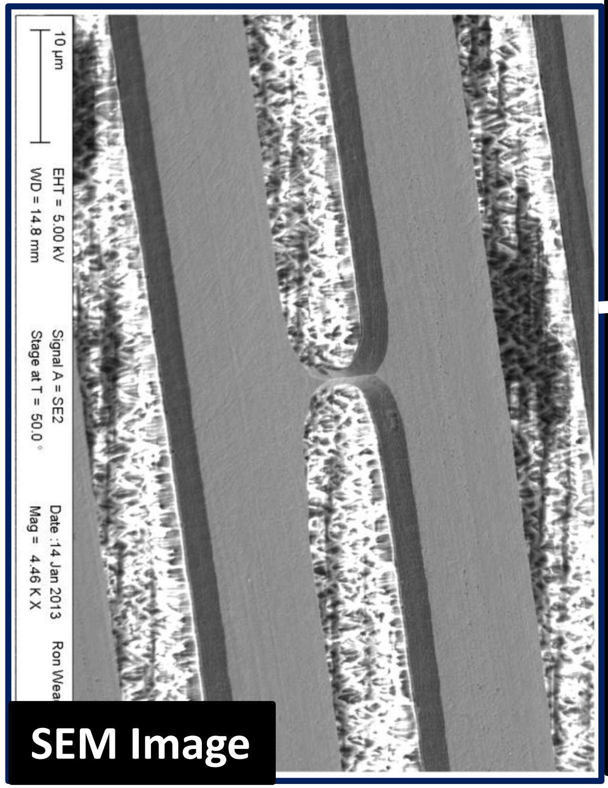
3. Reject resistors with *"hot spots"*

- Hot spots are indicative of constriction defects (e.g., notches, bridges, embedded particles)

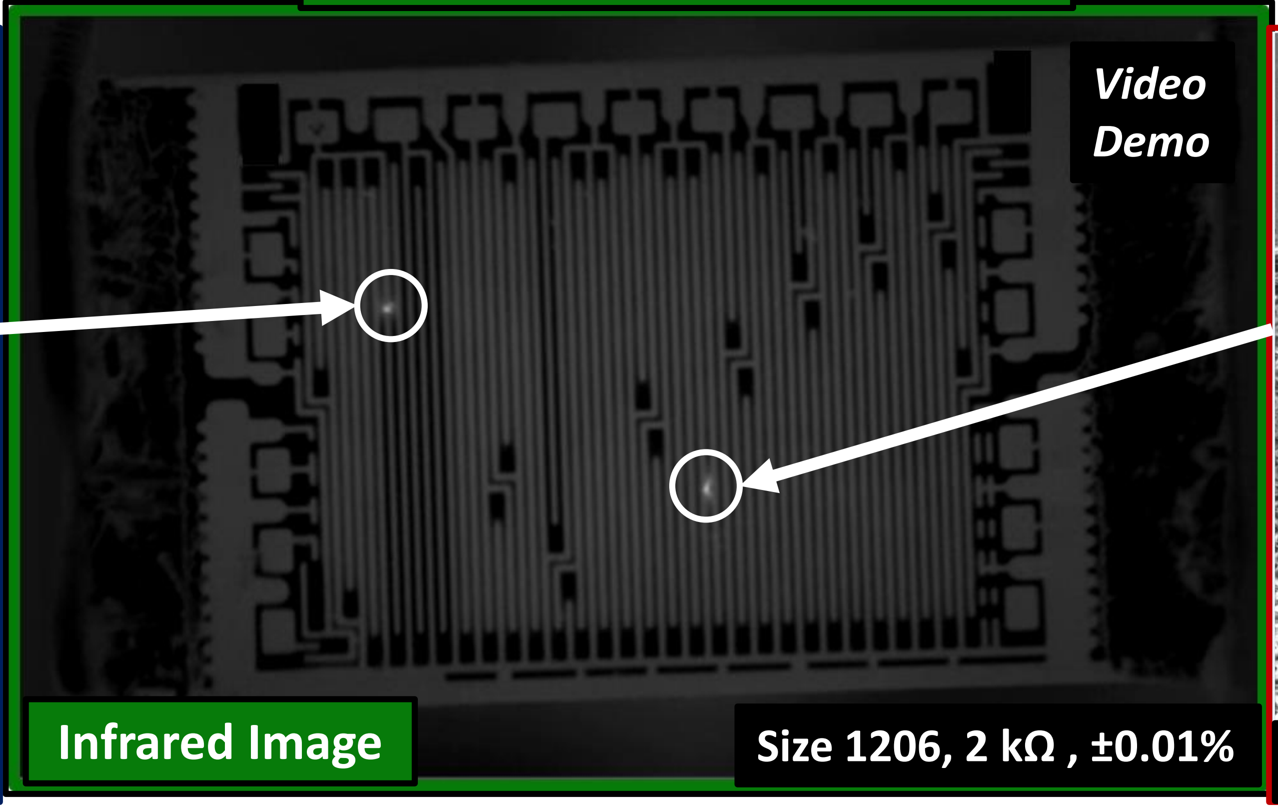
Demonstration of New Screening Method

Using DPA Sample with Bridge and Notch Defects

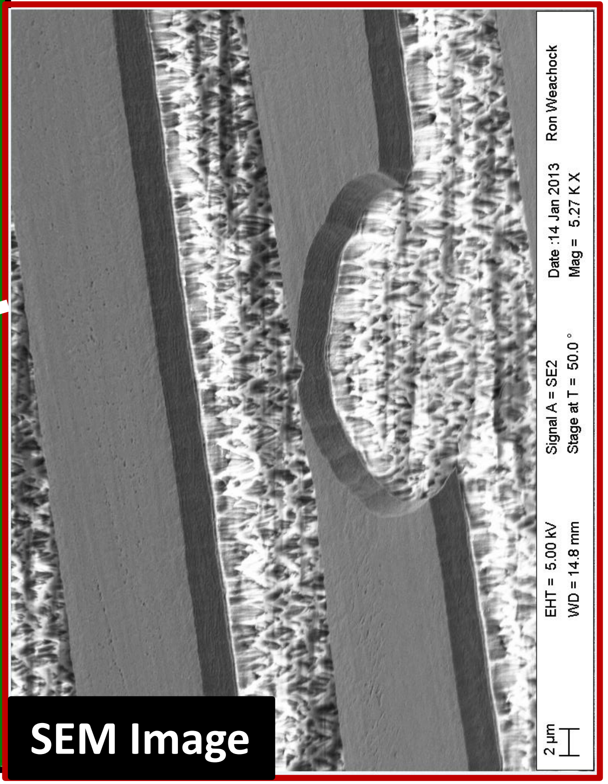
Bridge Defect



Pulsed-Power 6.25x Rated Power
50ms On / 150ms Off



Notch Defect

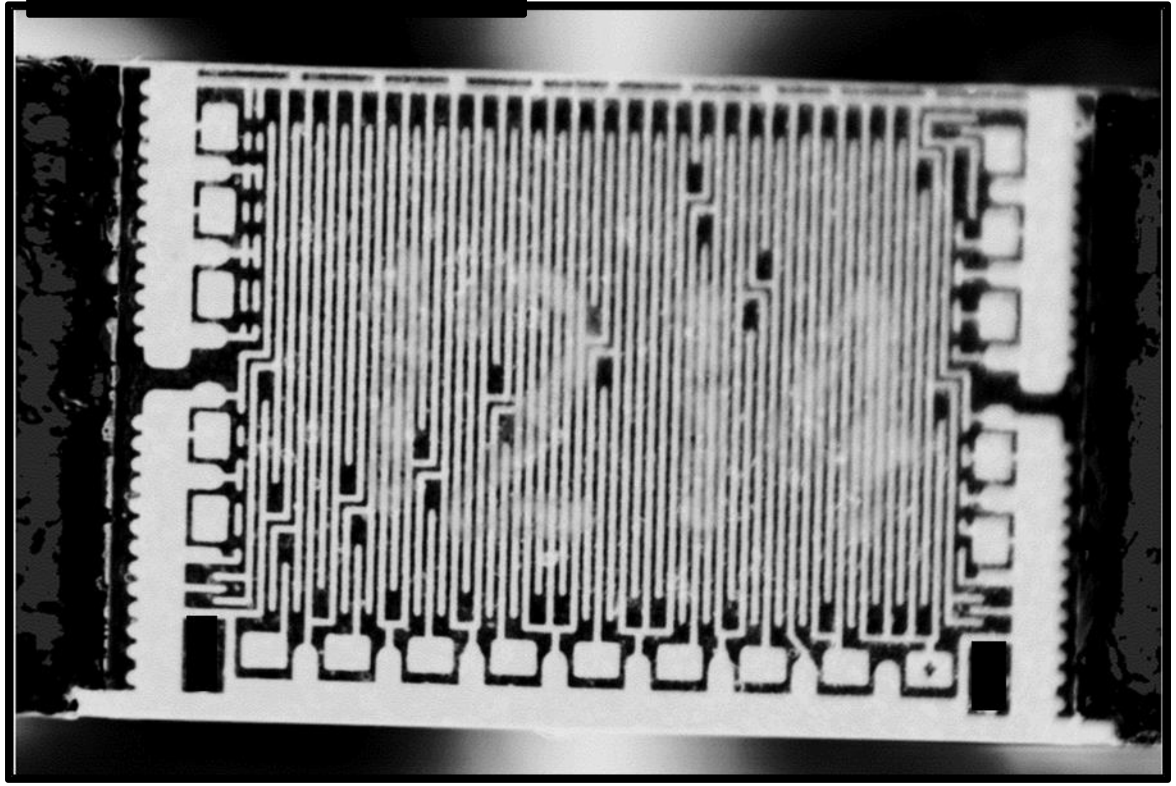


These Protective Coatings are "See Through" for Infrared Wavelengths of 3µm to 5µm Even With No Power Applied to the Resistor

Enables Post-Procurement Screening of SMT Foil Resistors

Optical Image

Infrared Image



Evaluation of New Screening Method

Obtain 280 SMT Foil Resistors **Types A, B & C*

↓

Characterize with Pulsed-Power Infrared

↓

10k Hour Life Test
1x Rated Power @ 70°C
1.5hrs ON / 0.5hrs OFF

↓

Repeat Pulsed-Power Infrared Characterization To Identify Changes

↓

Failure Analysis

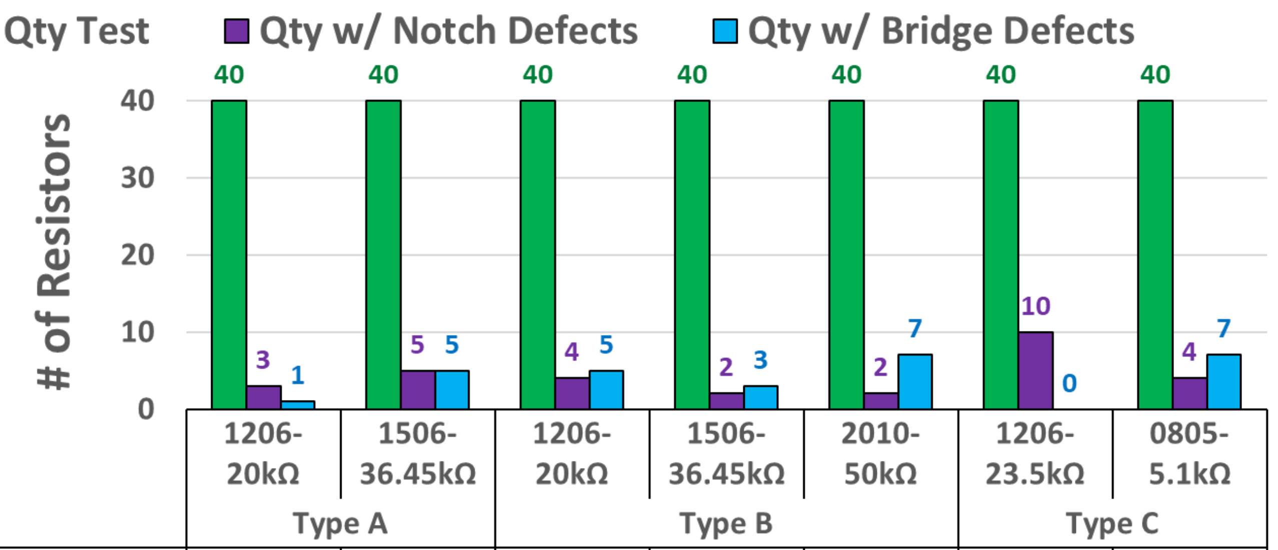
Foil Resistors Used for Evaluation

Resistor Size (EIA Footprint)	Resistance (Ω) & Tolerance	Power Rating (mW)	Qty	Resistor Pattern Geometry		* Type
				Foil Thickness (µm)	Foil Gridline Width (µm)	
0805	5.1k ± 0.05%	100	40	2.3	6.6	C
1206	20k ± 0.05%	150	40	2.5	4.8	A
1206	20k ± 0.05%	150	40	2.5	4.8	B
1206	23.5k ± 0.05%	150	40	2.3	4.3	C
1506	36.45k ± 0.05%	200	40	2.8	4.1	A
1506	36.45k ± 0.05%	200	40	2.8	4.1	B
2010	50k ± 0.01%	300	40	2.5	4.8	B
		Total	*280*			

*Type	Foil Classification	Pre-Encapsulation Screen	Powered Screening
A	Contains Some "Embedded Particles"	100% Visual Inspection	1x Short Time Overload (STOL)
B	"Particle-Free"	100% Visual Inspection	1x Short Time Overload (STOL)
C	"Particle-Free"	100% Visual Inspection	2x Short Time Overload (STOL)

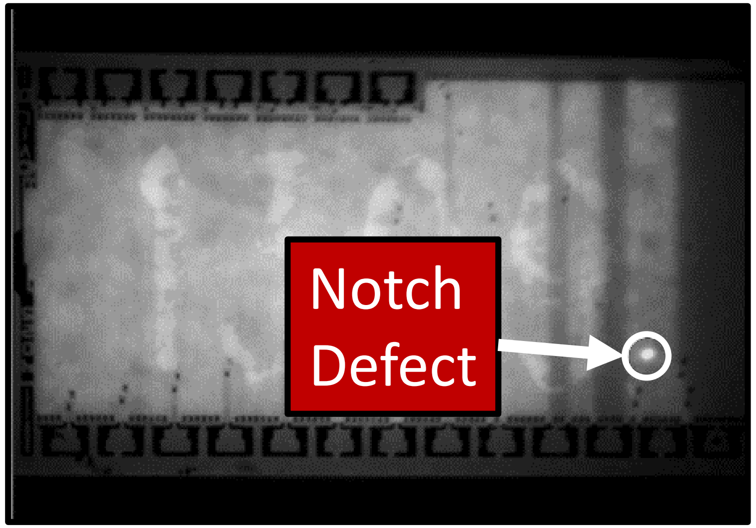
Results: Pre-Life Test Pulsed-Power Infrared Screening

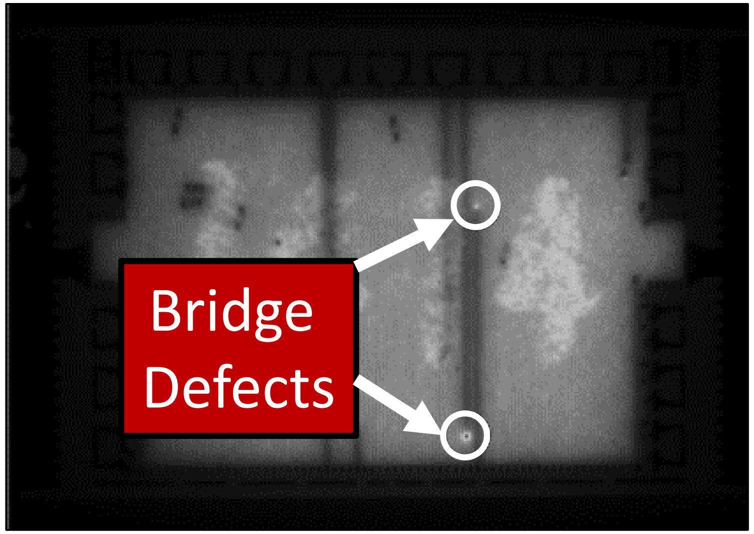
~10% to 25% of Resistors Per Lot Tested Had Constriction Defects



	Type A		Type B			Type C	
	1206-20kΩ	1506-36.45kΩ	1206-20kΩ	1506-36.45kΩ	2010-50kΩ	1206-23.5kΩ	0805-5.1kΩ
Qty Test	40	40	40	40	40	40	40
Qty w/ Notch Defects	3	5	4	2	2	10	4
Qty w/ Bridge Defects	1	5	5	3	7	0	7

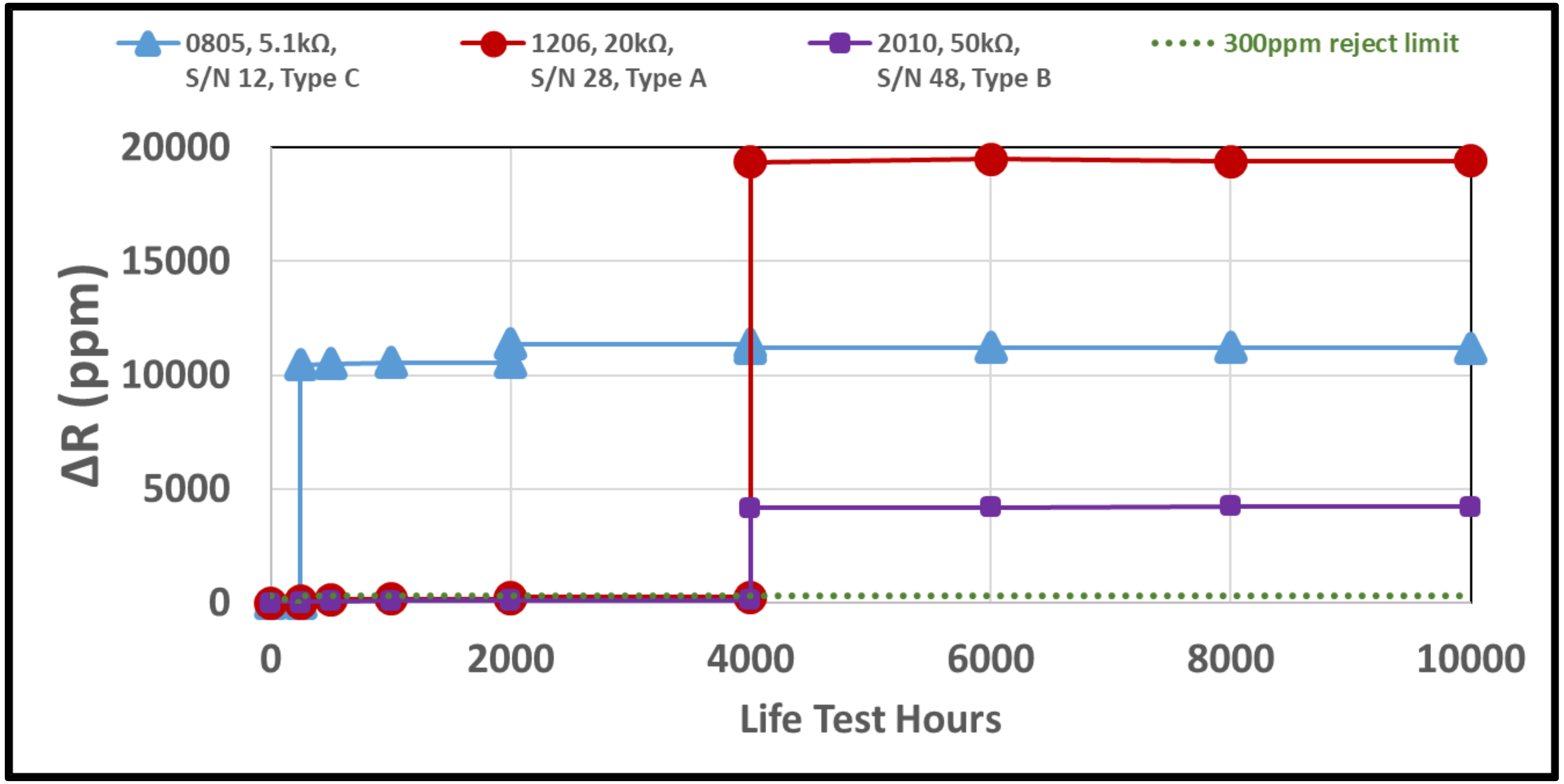
Totals
280 Tested
30 with Notch Defects
28 with Bridge Defects

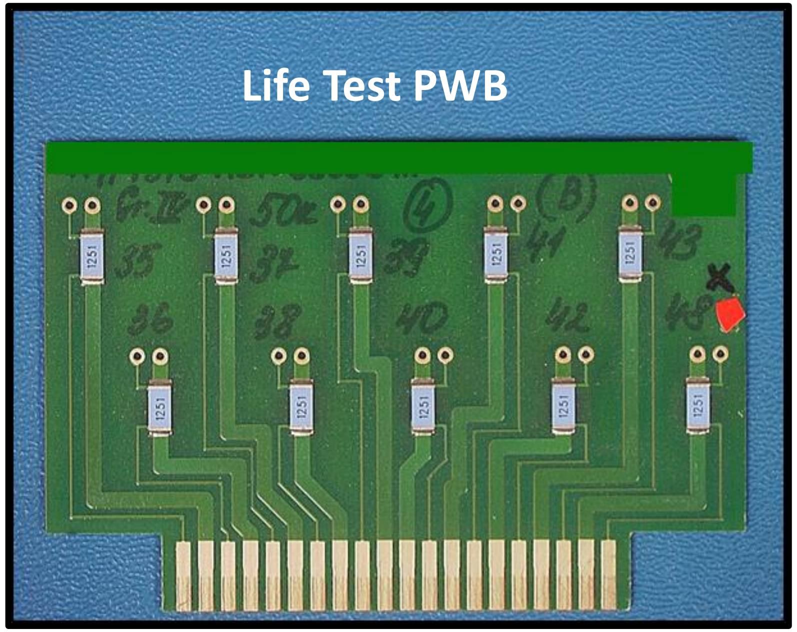




Results: 3 Life Test Failures (280 Resistors Tested)

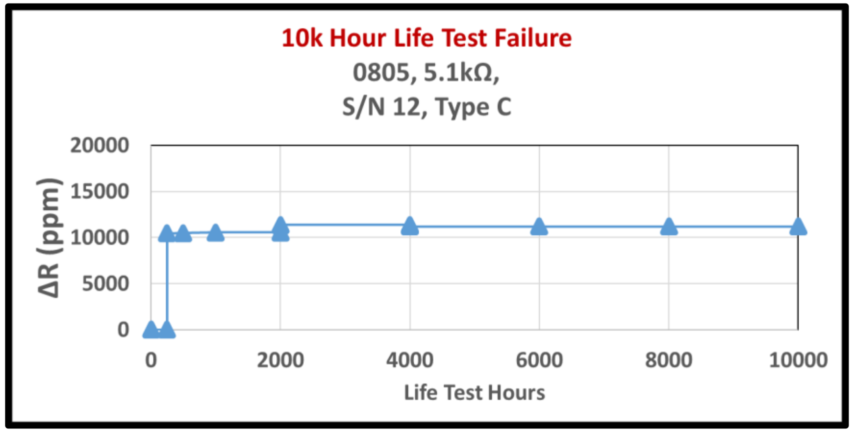
Abrupt Positive Resistance Shift Failure Modes





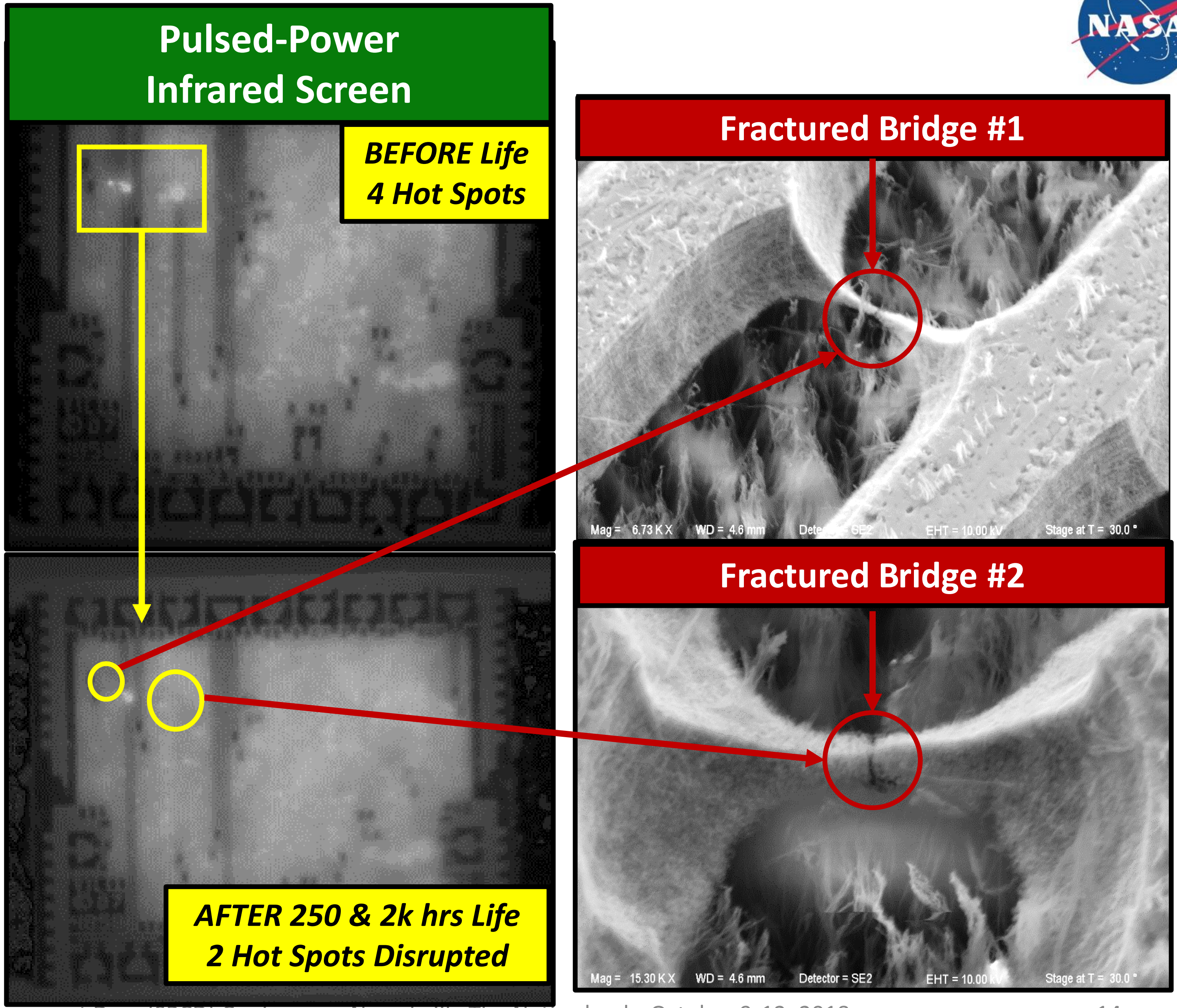
**   S/N 12 exhibits 2 distinct positive shifts during life test*

Failure Analysis:
0805, 5.1kΩ, S/N 12, Type "C"

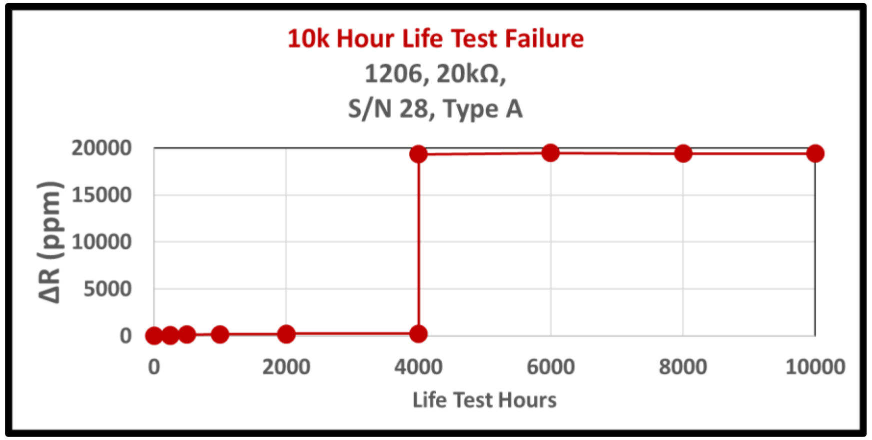


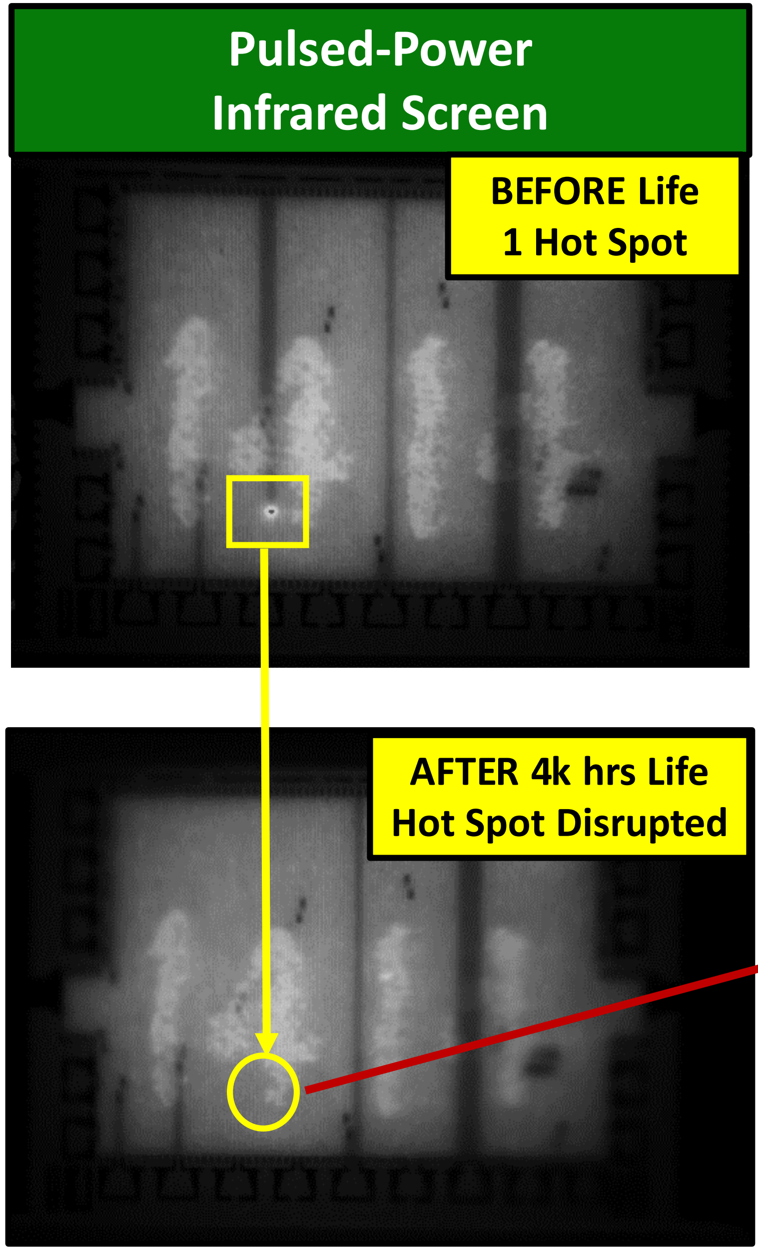
Conclusion:
Two ***bridge defects fractured*** **during life test causing total ΔR ~11000 ppm**

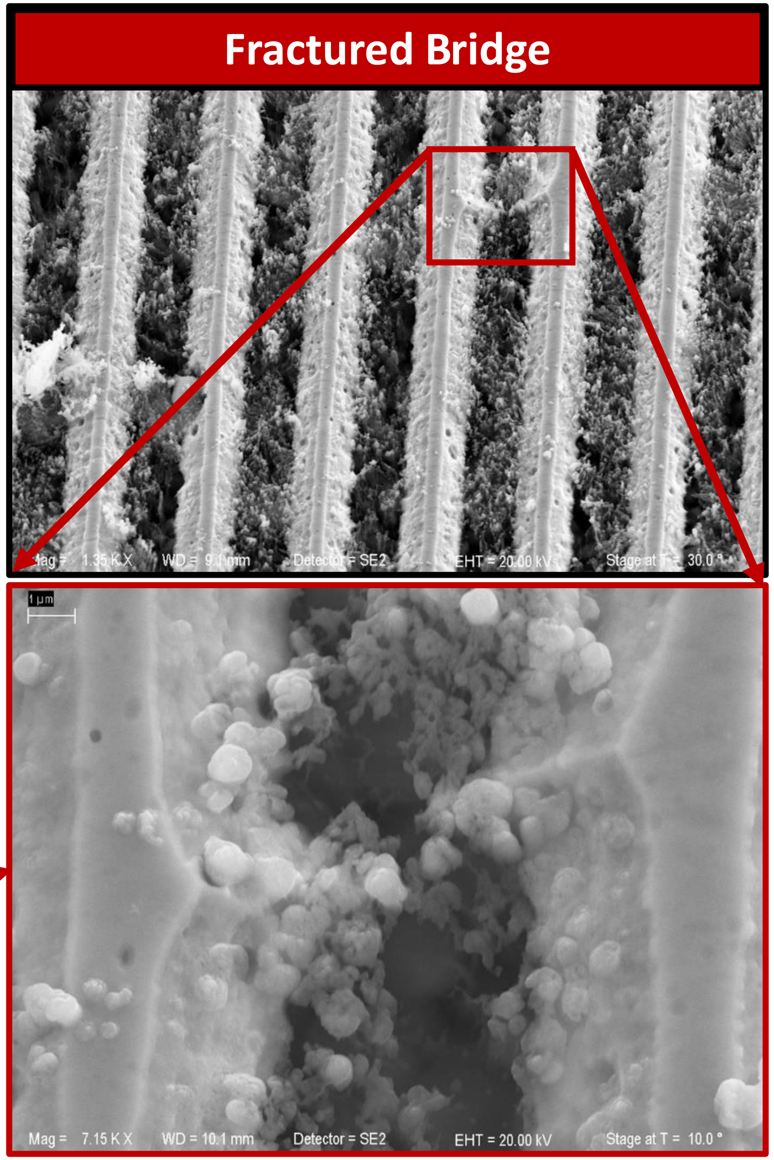
Pulsed-Power Infrared Screen detected both bridge defects as 'hot spots' BEFORE Life Test



Failure Analysis:
1206, 20kΩ, S/N 28, Type "A"





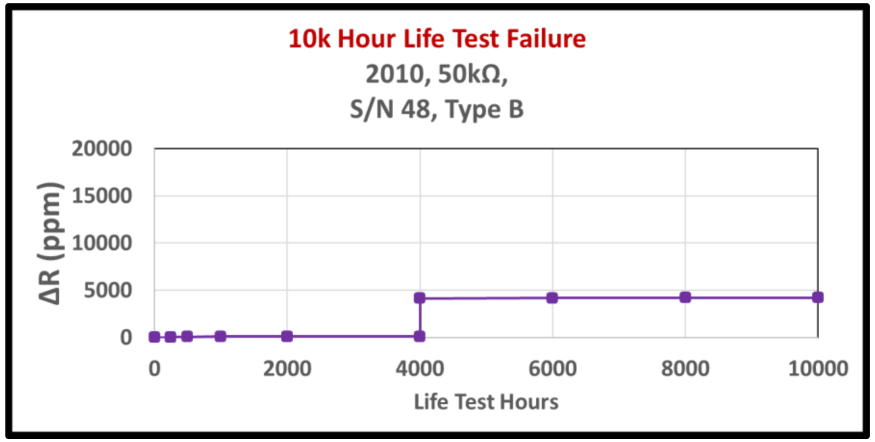


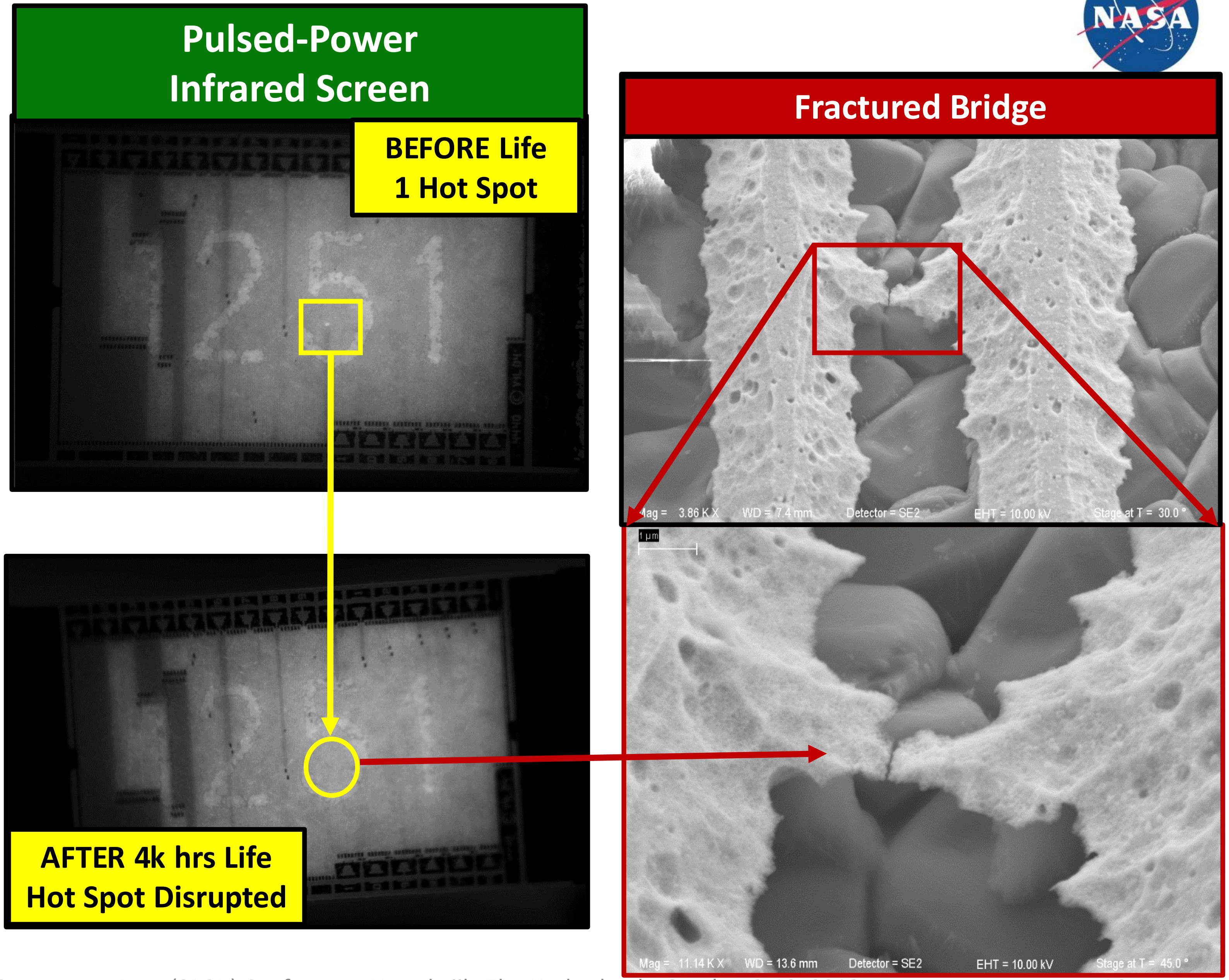
Conclusion:
One bridge defect fractured **during life test causing ΔR ~19400 ppm**

Pulsed-Power Infrared Screen detected this bridge defect as a 'hot spot' BEFORE Life Test

Failure Analysis:

2010, 50kΩ, S/N 48, Type "B"





Conclusion:

One bridge defect fractured **during life test causing ΔR ~4200 ppm**

Pulsed-Power Infrared Screen detected this bridge defect as a 'hot spot' BEFORE Life Test

Conclusions

1. **Resistor failures (i.e., positive ΔR and open circuit) sometimes occur due to thermomechanically-induced fatigue fracture of localized constriction defects in the resistor pattern (e.g., notches, bridges, embedded particles).**

2. **Standard screening techniques (e.g., pre-encapsulation visual, STOL, DPA) Do NOT detect all resistors with significant constriction defects in the resistor pattern.**

3. **New Pulsed-Power Infrared Screening technique has been developed**

   - ***Detects localized constriction defects as "hot spots" using high resolution infrared thermography***
   - ***Proven effective via 10k hour life test with failure analyses correlating pre-existing constriction defects to 'hot spots' and subsequent fractured constrictions after life test***
   - ***Suitable for use as an 'In-Process Manufacturer Screening Inspection' prior to encapsulation And as a non-destructive 'Post-Procurement' screen for SMT foil resistors***

New Screening Technique Can Take a Super Stable Resistor Technology and Make it Super Reliable Too

Acknowledgements

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Jack Shue NASA Goddard Space Flight Center Office of Safety and Mission Assurance	**Alexandros Bontzos, Chris Greenwell,** **Tim Mondy, Nilesh Shah,** **Ron Weachock** NASA Goddard Space Flight Center Parts Analysis Laboratory

Foil Resistor Samples and Life Testing Services Provided by
Vishay Precision Group (VPG)

Backup Slides

High Resolution Infrared Camera with 4x lens option

FLIR SC8200, SC8300 Series

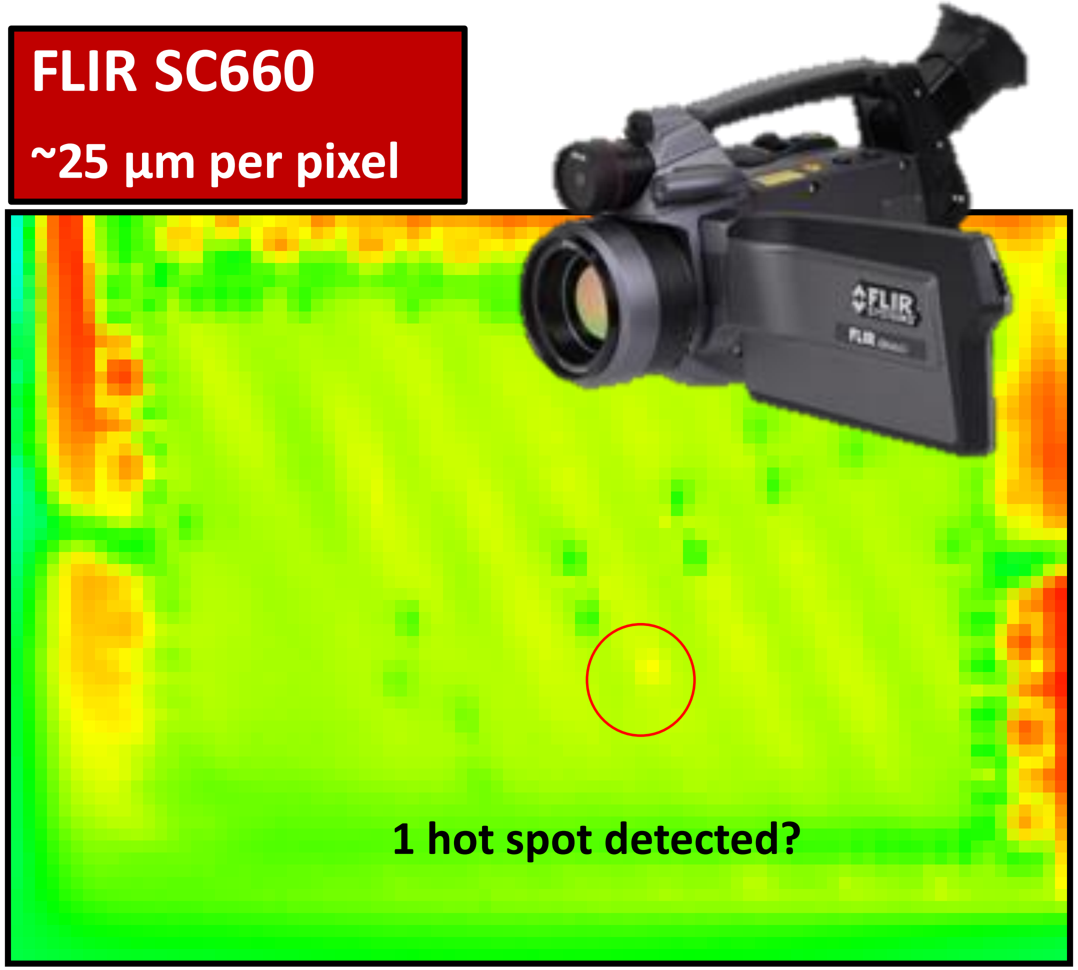
Parameter	Specification
Detector	InSb
Spectral Range	3 µm to 5 µm
Measurement Temperature Range	-20°C to +350°C
Field of View	~4.6mm x 5.6mm (> 1 million pixels)
Resolution	~ 5 µm per pixel
Focal Working Distance	~25mm
Frame Capture Rate	>100 frames per second (fps)

Comparison of Two Different Infrared Cameras

Inspecting the same resistor with 2 constriction defects while applying power pulses

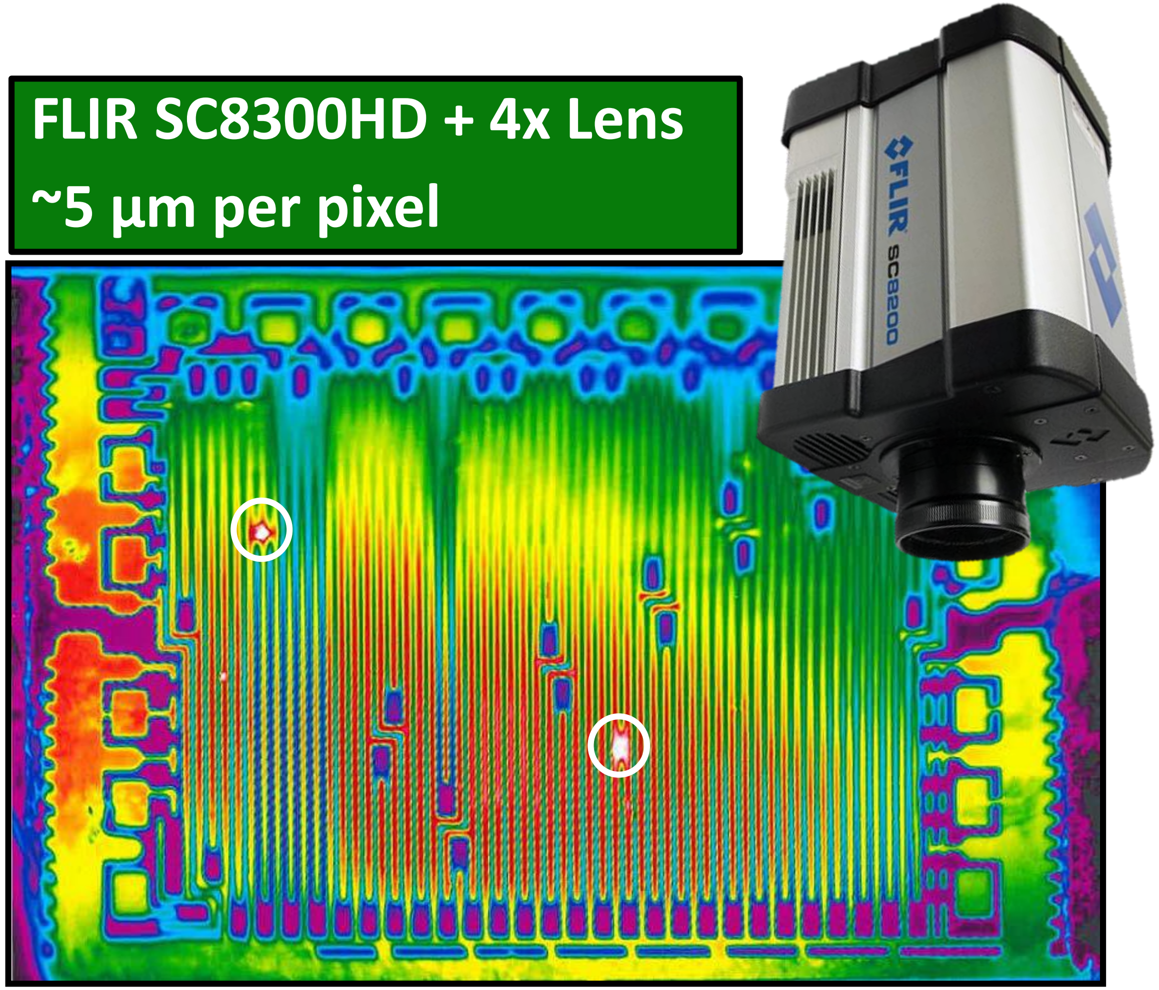
FLIR SC660

~25 µm per pixel



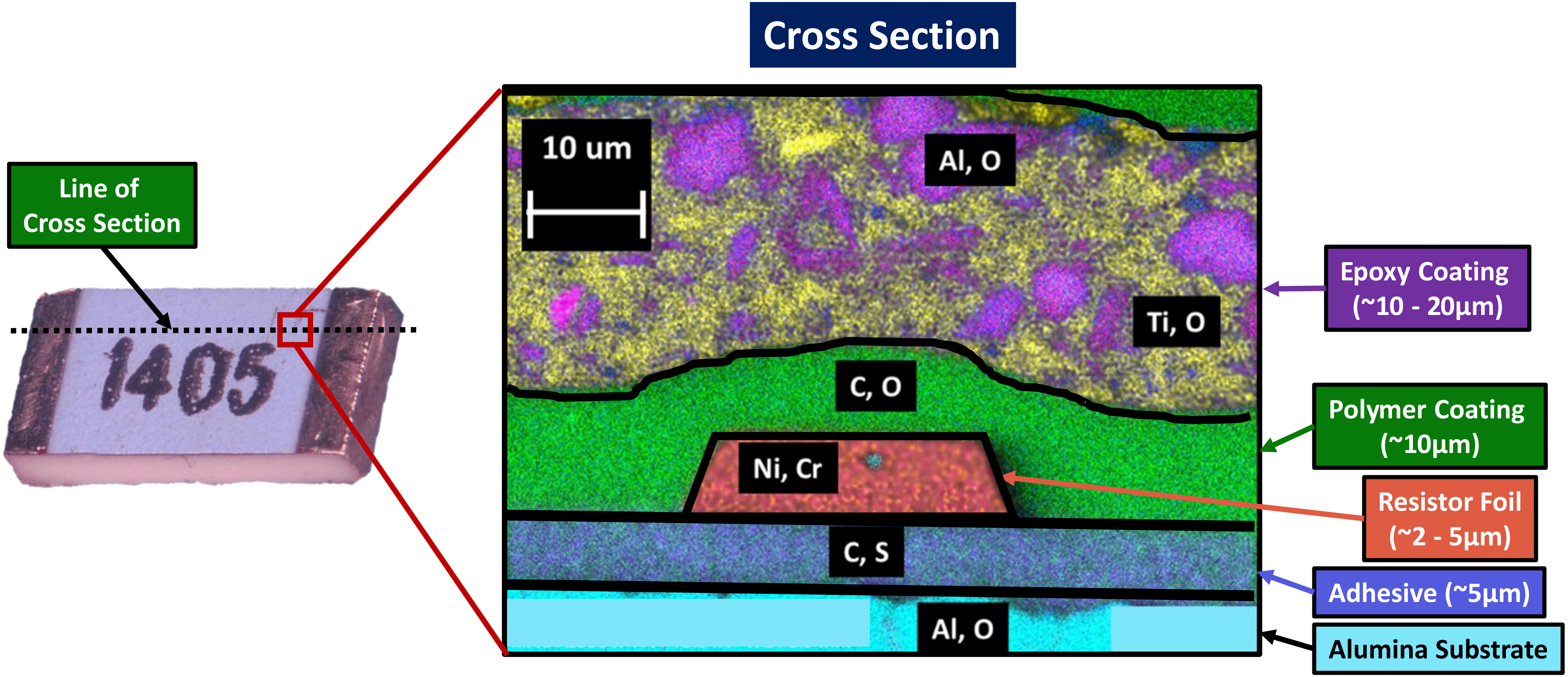
FLIR SC8300HD + 4x Lens

~5 µm per pixel



Basic Construction of a SMT Foil Resistor

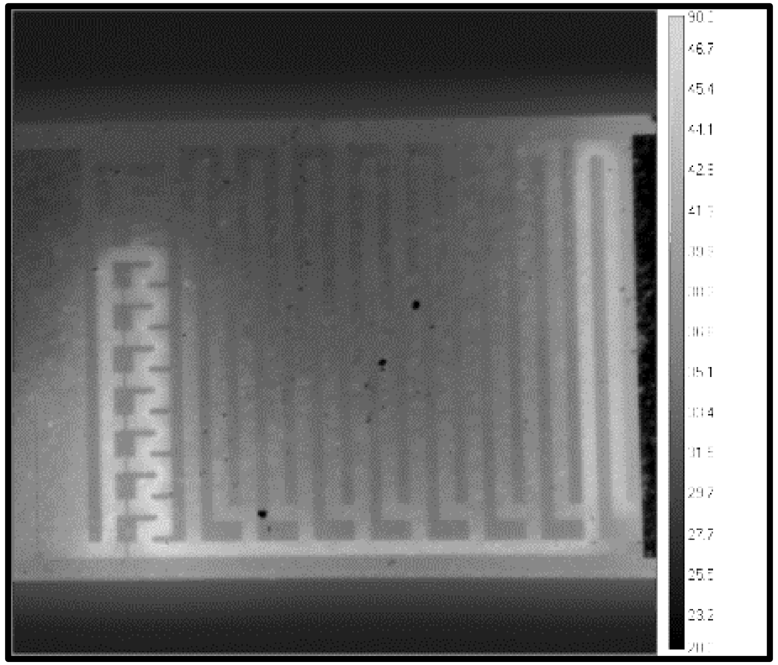
Cross Section

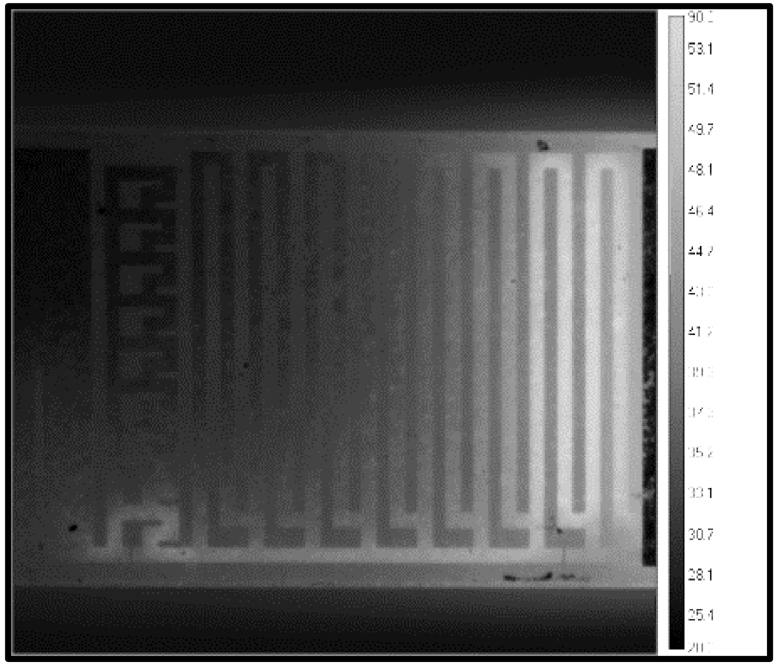


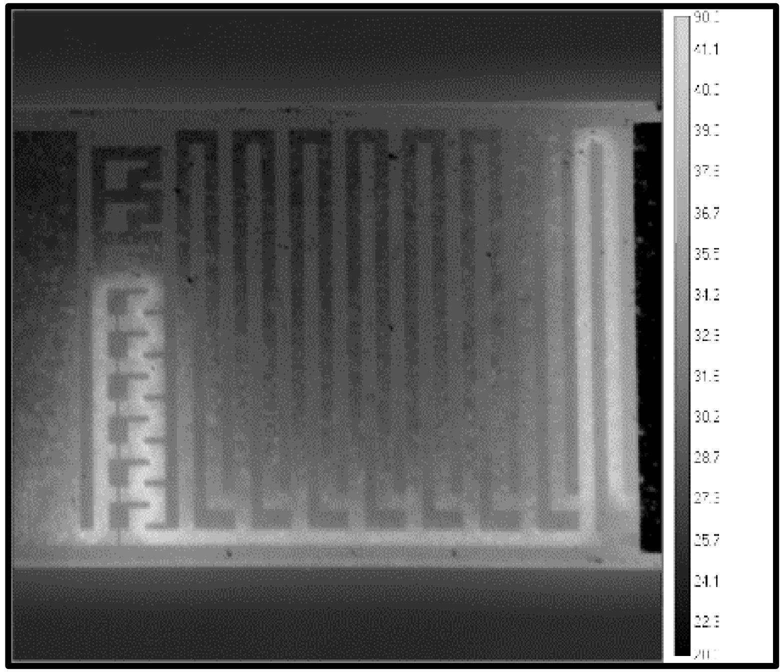
SMT Thin Film Resistors Inspected Using New Pulsed-Power Infrared Screening Method

Applying 6.25x Rated Power for 100 ms pulses; 10% duty cycle

Infrared Inspection Performed Without Removing Resistor Protective Coatings

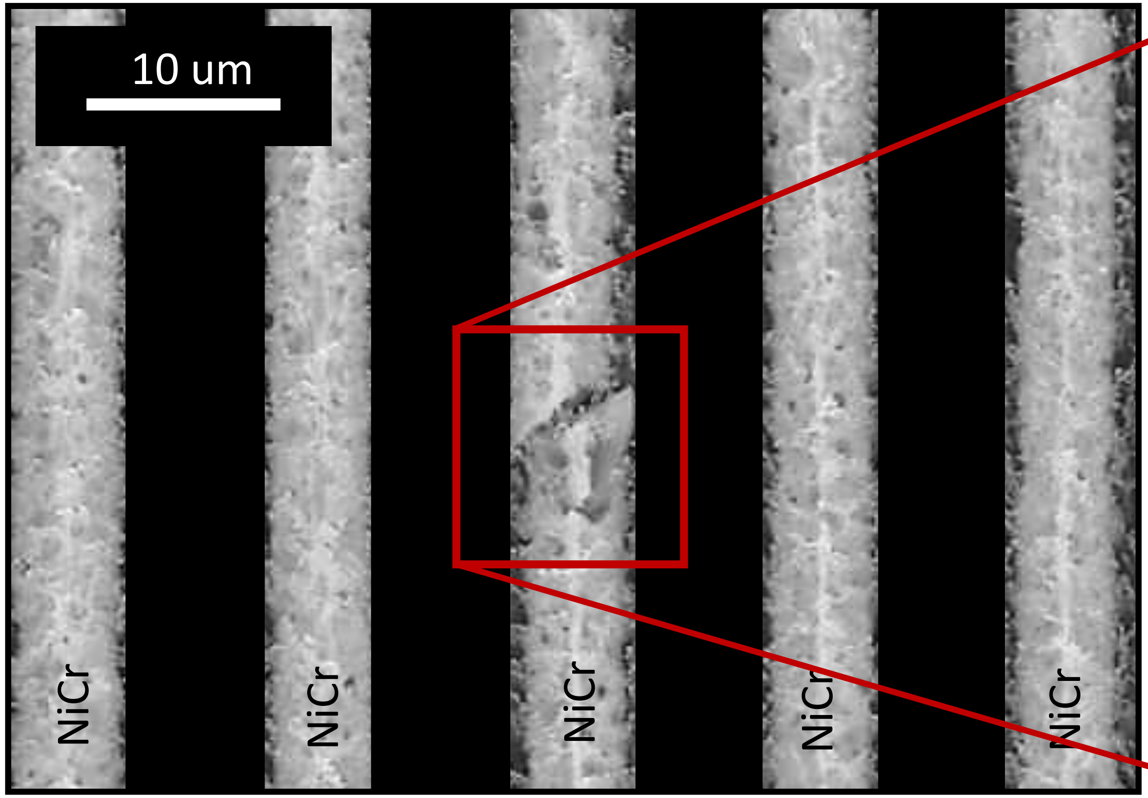




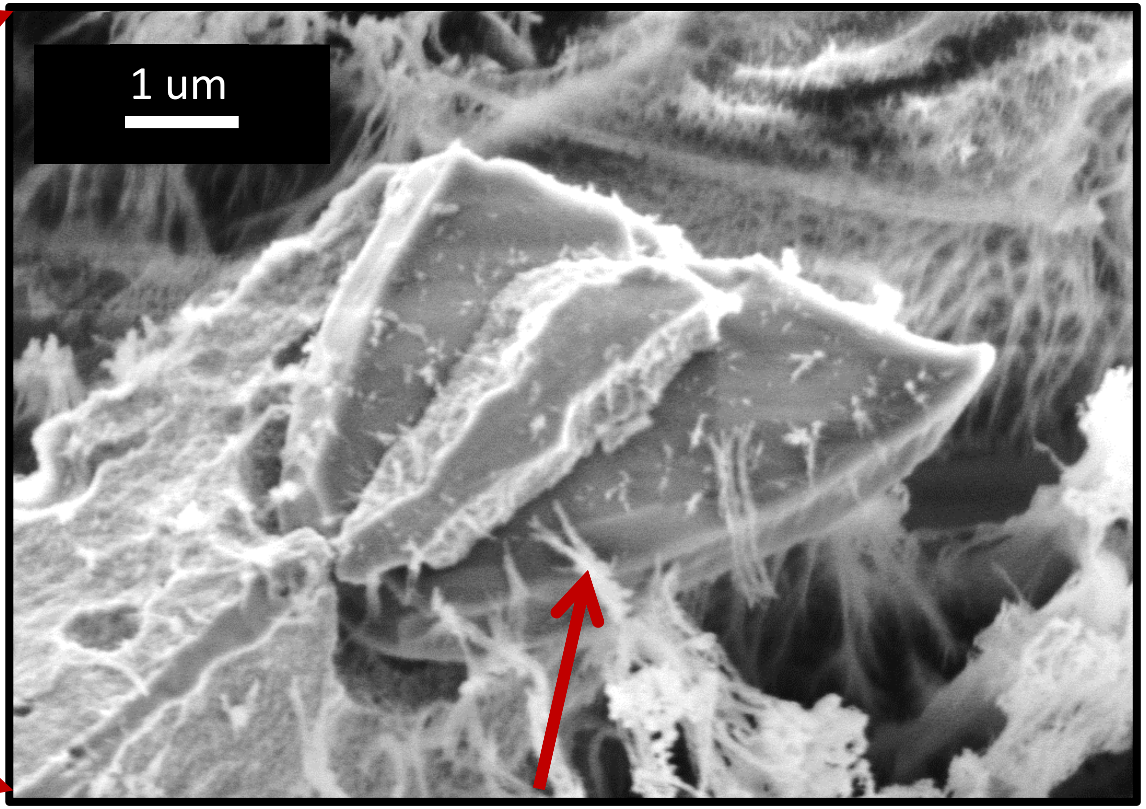


A Case for an Improved Screening Method:

Embedded Al-N Particle in Foil Resistor Size 1206, 30 kΩ



Fractured NiCr Gridline With Embedded Al-N Particle



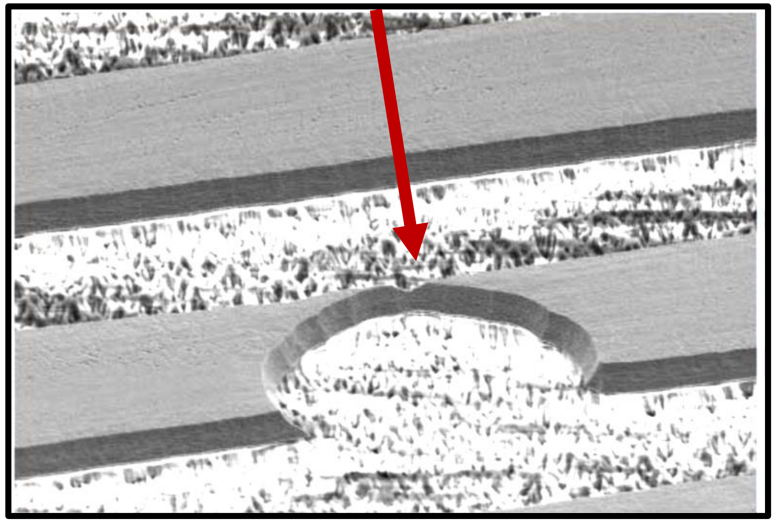
Aluminum Nitride Particle

Traditional Resistor Screening Methods

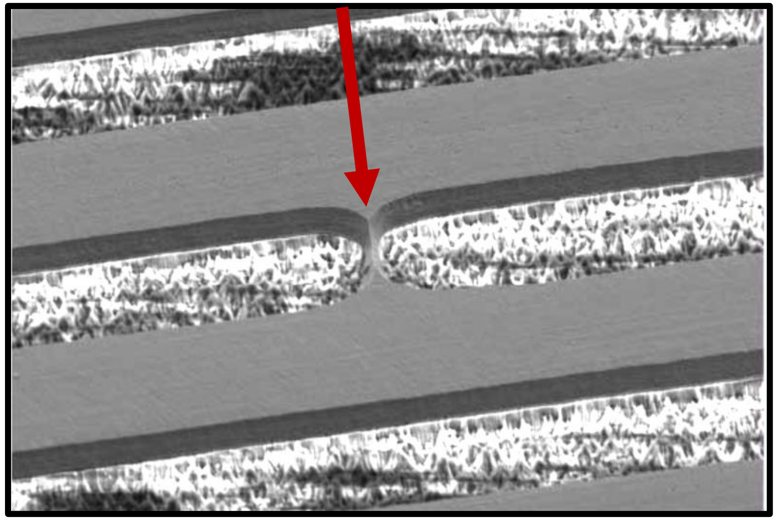
Optical Microscopy

	Thin Film (MIL-PRF-55342)	Foil Resistors
Test Conditions	30x to 60x optical microscopy prior to encapsulation	
Sample Size	100% in-process screen	100% high reliability products only
Rejection Criteria	Voids > 50% nominal line width Bridges < 50% smallest line width	Voids > 75% nominal line width Bridges < 10% smallest line width

Void > 75% in Foil Resistor



Bridge < 10% in Foil Resistor



Traditional Resistor Screening Methods

Short Time Overload (STOL)

	Thin Film (MIL-PRF-55342)	Foil Resistors
Test Conditions	6.25x rated power for 5 seconds	
Sample Size	20 pcs (space level only)	10 pcs (high reliability products)
Rejection Criteria	$\Delta R > 0.1\%$	$\Delta R > 0.02\%$

STOL may sometimes force failure of devices with the most severe pattern constrictions

Traditional Resistor Screening Methods

Power Conditioning

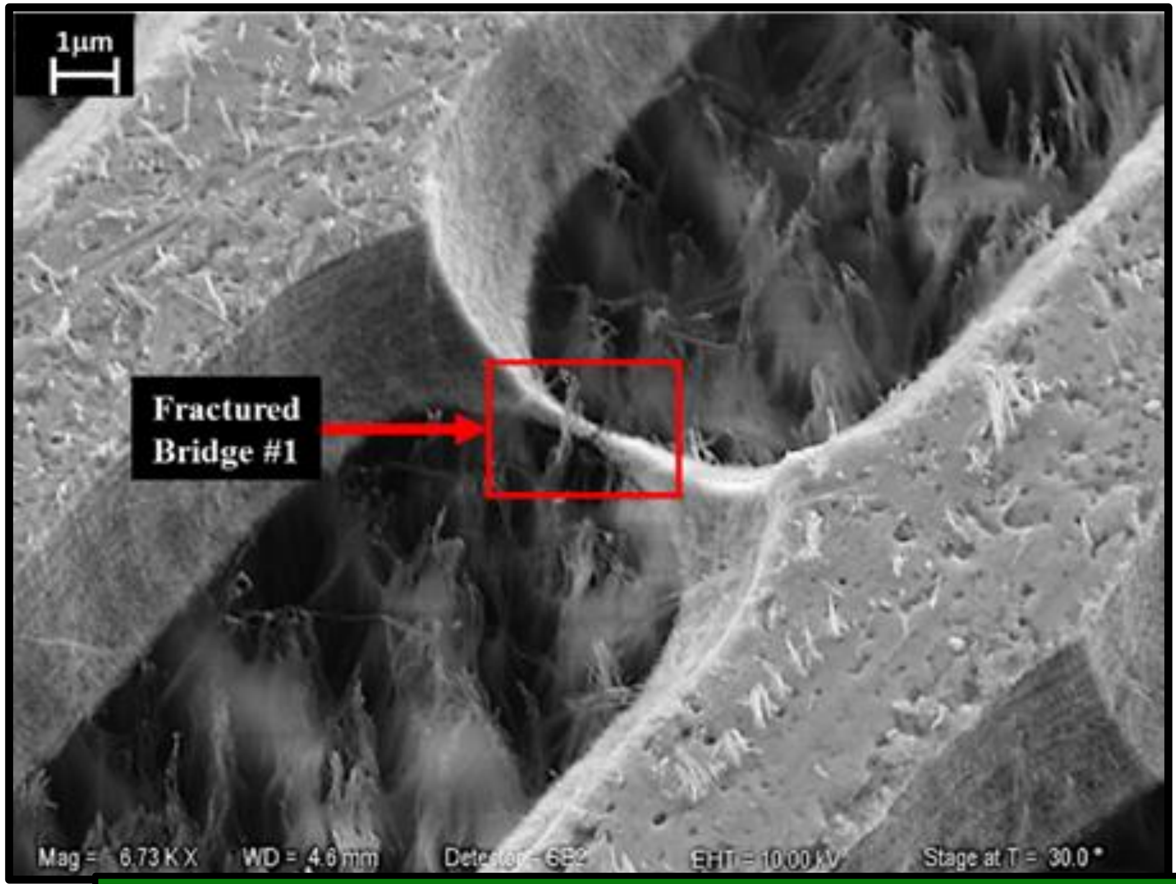
	Thin Film (MIL-PRF-55342)	Foil Resistors
Test Conditions	1.5x rated power for 100 hours at 70°C	
Sample Size	100% (space level only)	100% (high reliability products only)
Rejection Criteria	$\Delta R > 0.2\%$	$\Delta R > 0.03\%$

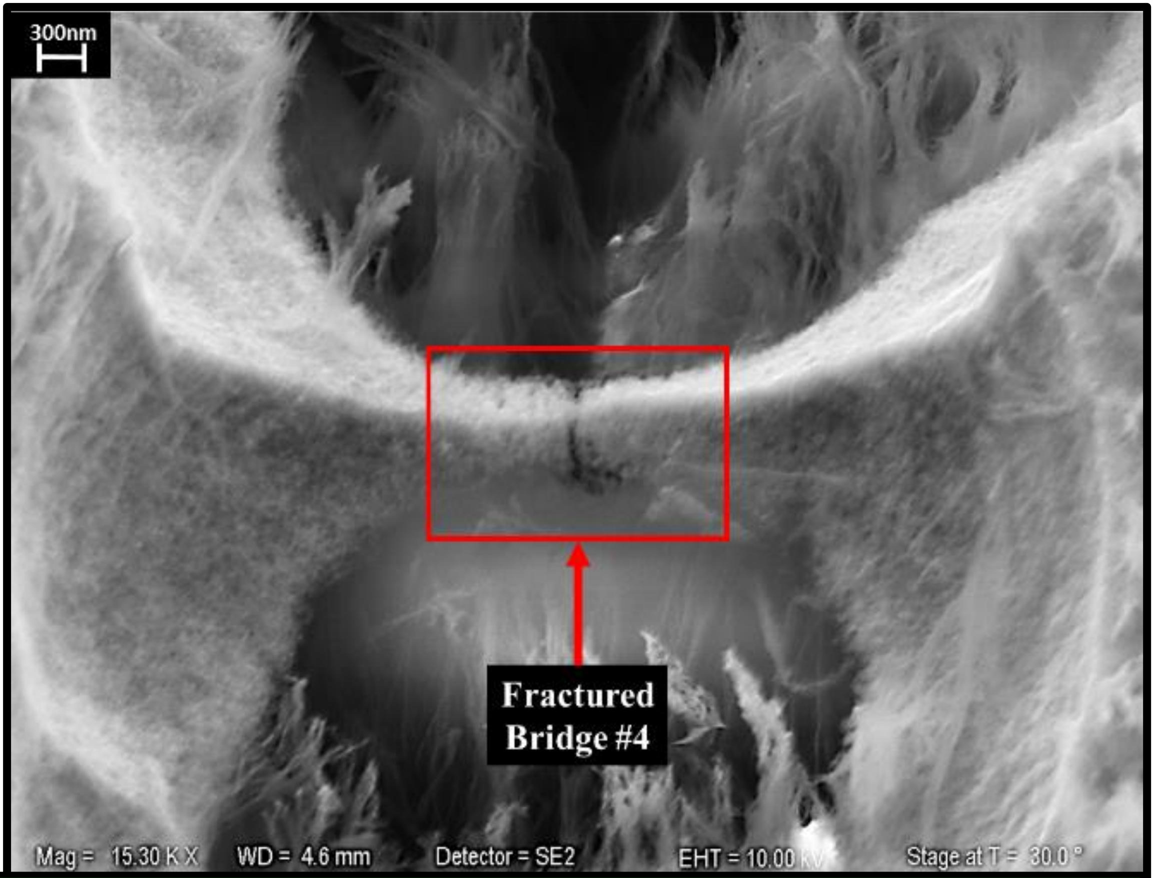
Power Conditioning may sometimes force failure of devices with the most severe pattern constrictions

Failure Analysis

0805, 5.1kΩ, S/N 12, Type "C"

Two Positive Resistance Shifts During Life Test *ΔR1 = +10440ppm @ 250 hrs; ΔR2 = +815ppm @ 2000 hrs*





Conclusion:
This Resistor Exhibited Two Abrupt Positive ΔR Shifts During Life Test.
Both Shifts Were Caused by Thermomechanically-Induced Fatigue Fracture of Two Separate Foil Bridge Defects