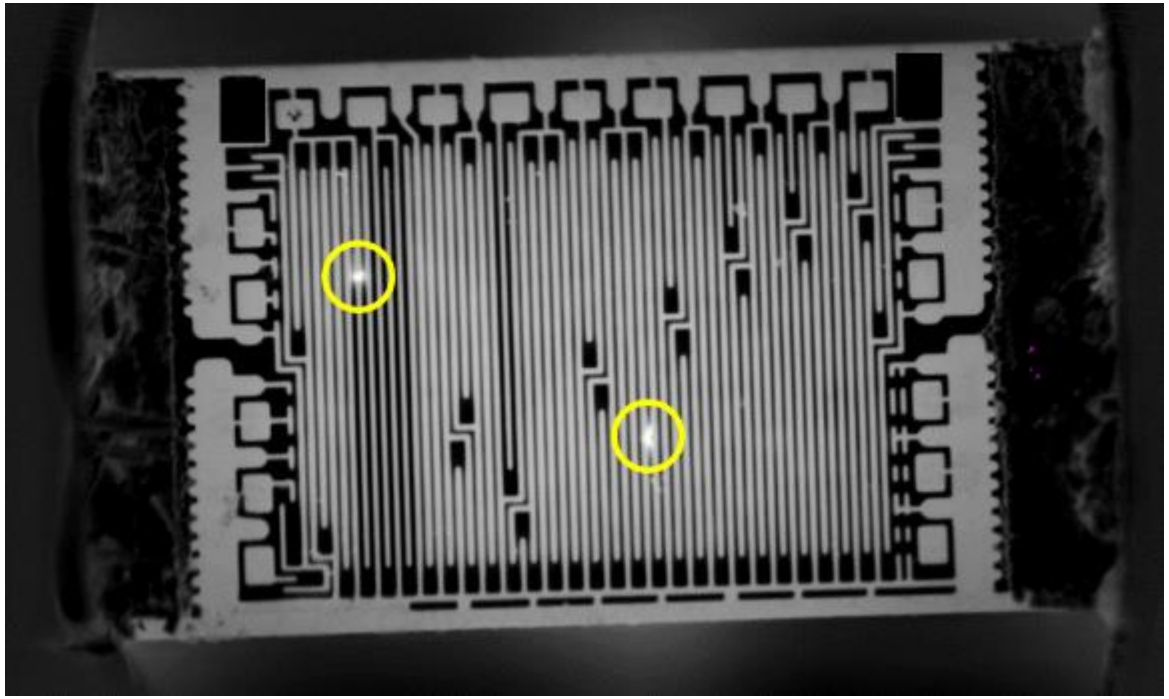
A Screening Method Using Pulsed-Power Combined with Infrared Imaging to Detect Pattern Defects in Bulk Metal Foil or Thin Film Resistors



Jay Brusse

SSAI/NASA Goddard Space Flight Center

Lyudmyla Ochs

NASA Goddard Space Flight Center

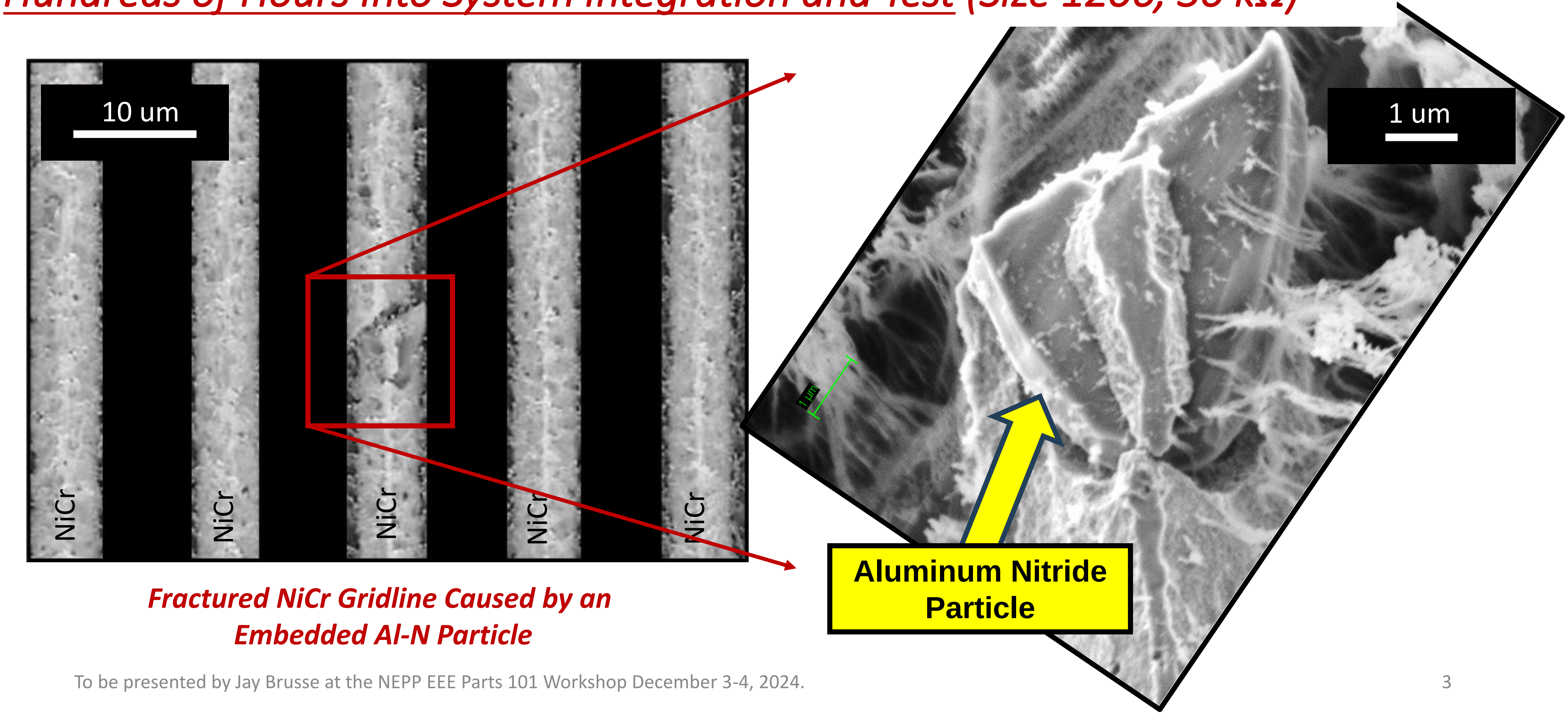
To be presented by Jay Brusse at the NEPP EEE Parts 101 Workshop December 3-4, 2024.

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

A MOTIVIATION for an Improved Screening Method:

NASA Program Experienced an OPEN CIRCUIT FAILURE of a FOIL RESISTOR Hundreds of Hours Into System Integration and Test (Size 1206, 30 kΩ)

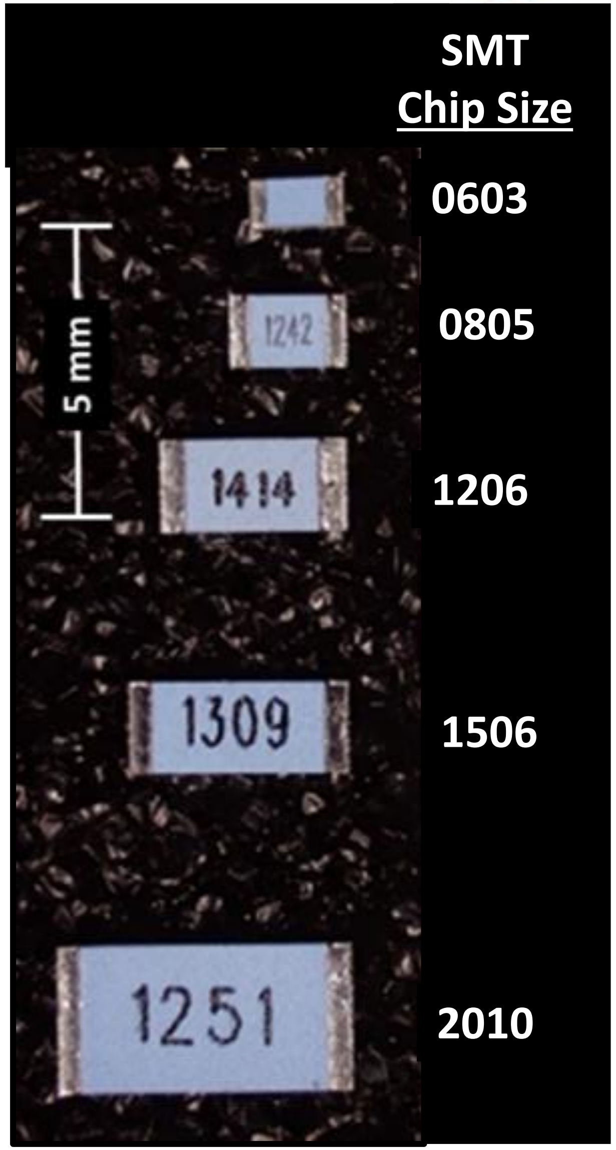


Aluminum Nitride Particle

Fractured NiCr Gridline Caused by an Embedded Al-N Particle

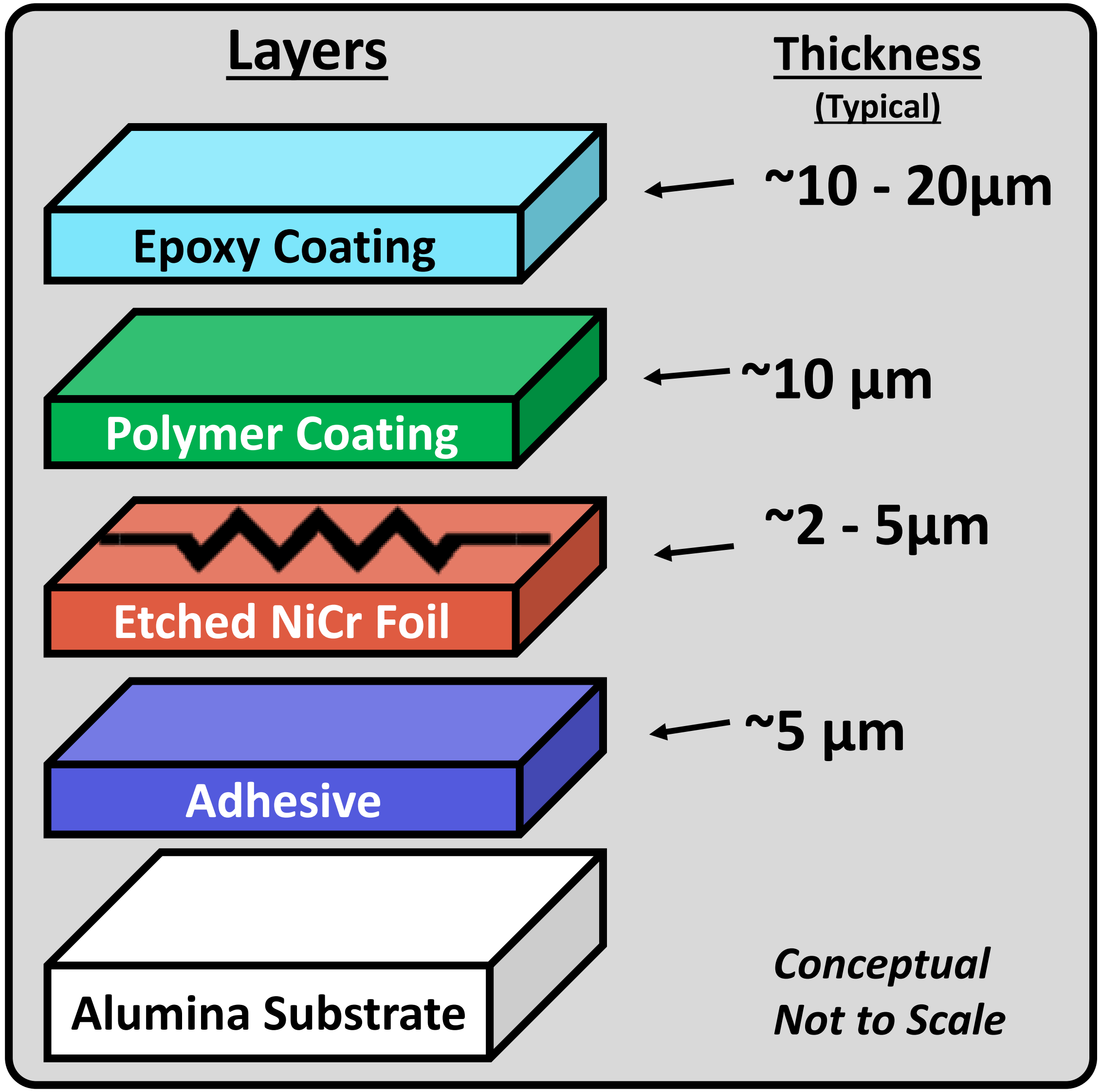
Foil Resistors Have Many Favorable Attributes

Attribute	
Package Configurations	Surface Mount Technology (SMT); Through Hole
Resistance Values	Custom Values; 5Ω to 240kΩ (standard SMT)
Resistance Tolerance	± 0.01% (± 100 ppm)
Temperature Coefficient of Resistance (TCR)	< ± 0.2 ppm/°C from -55°C to +125°C
Load Life Stability	± 0.02% (± 200ppm) after 2k hour life test @ 1x rated power @ 70°C



Basic Construction of a SMT Foil Resistor

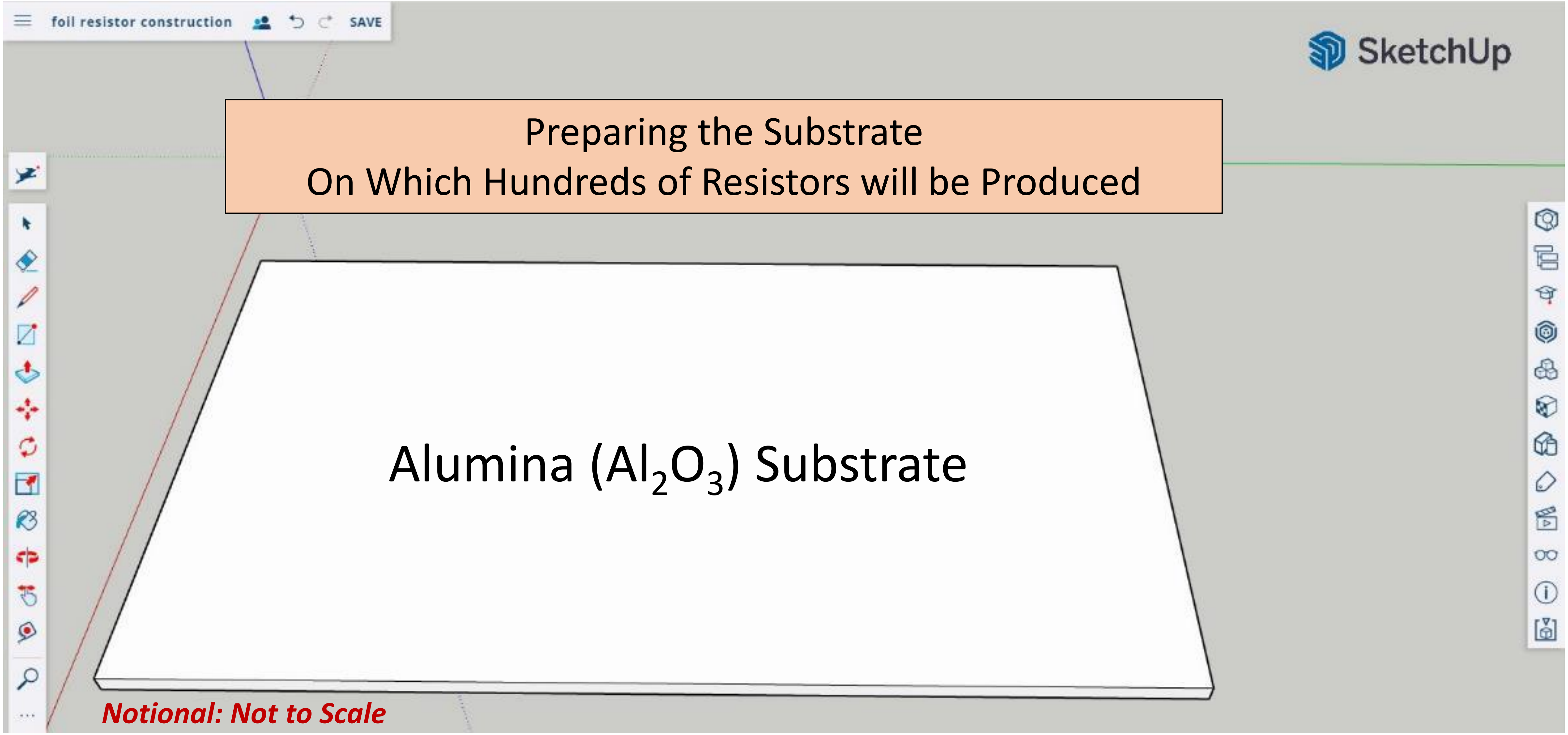
- Resistor element is made from foil sheets of NiCr-based alloys
- Resistor gridline patterns are created by photolithography and electrochemical etching
- Resistor foil is adhesively-bonded to an alumina substrate
- Precise resistance values achieved by laser or mechanical cutting of combinations of "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



Layers	Thickness (Typical)
Epoxy Coating	~10 - 20µm
Polymer Coating	~10 µm
Etched NiCr Foil	~2 - 5µm
Adhesive	~5 µm
Alumina Substrate	

Conceptual Not to Scale

Primary Materials and Production Steps for Foil Resistors

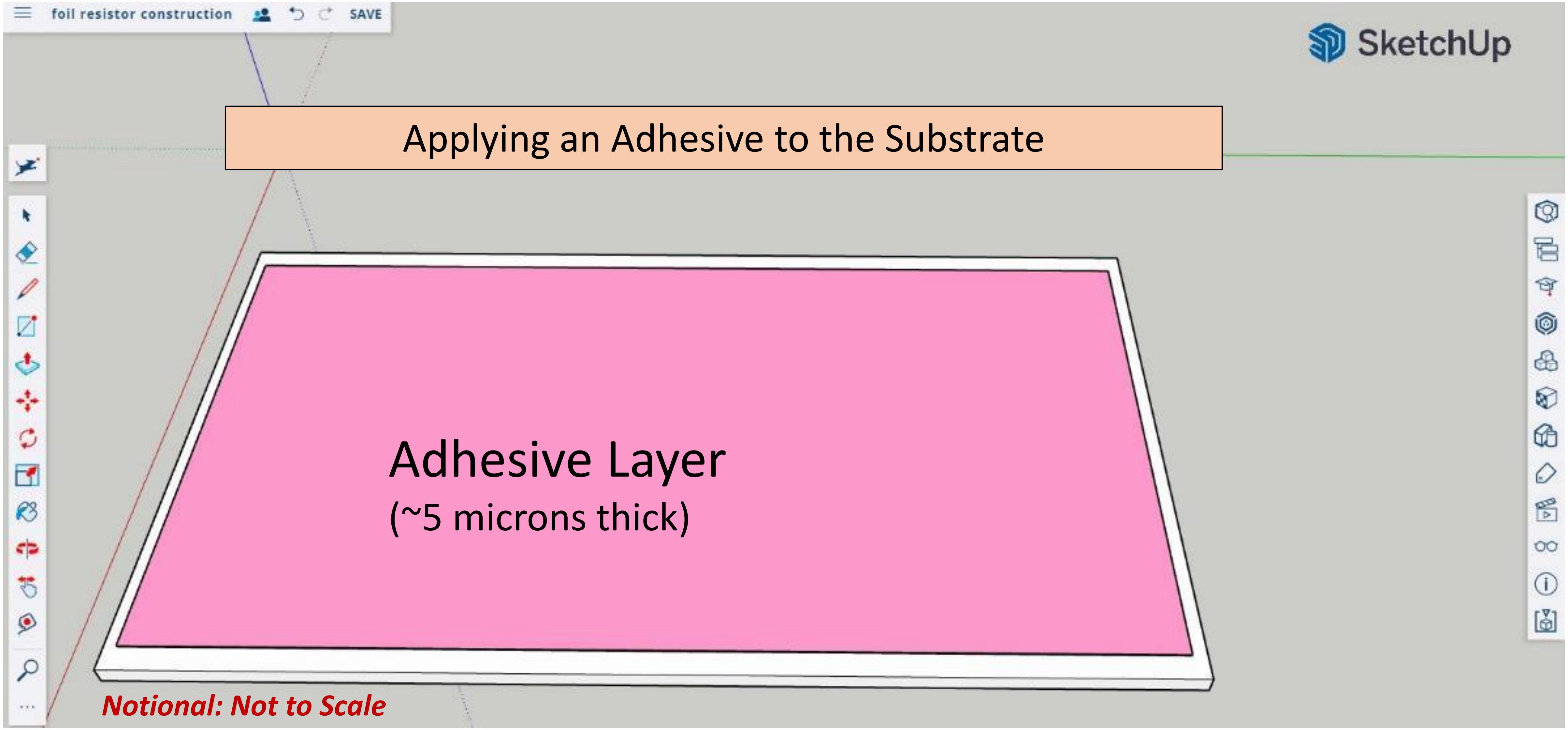


Preparing the Substrate
On Which Hundreds of Resistors will be Produced

Alumina (Al_2O_3) Substrate

Notional: Not to Scale

Primary Materials and Production Steps for Foil Resistors

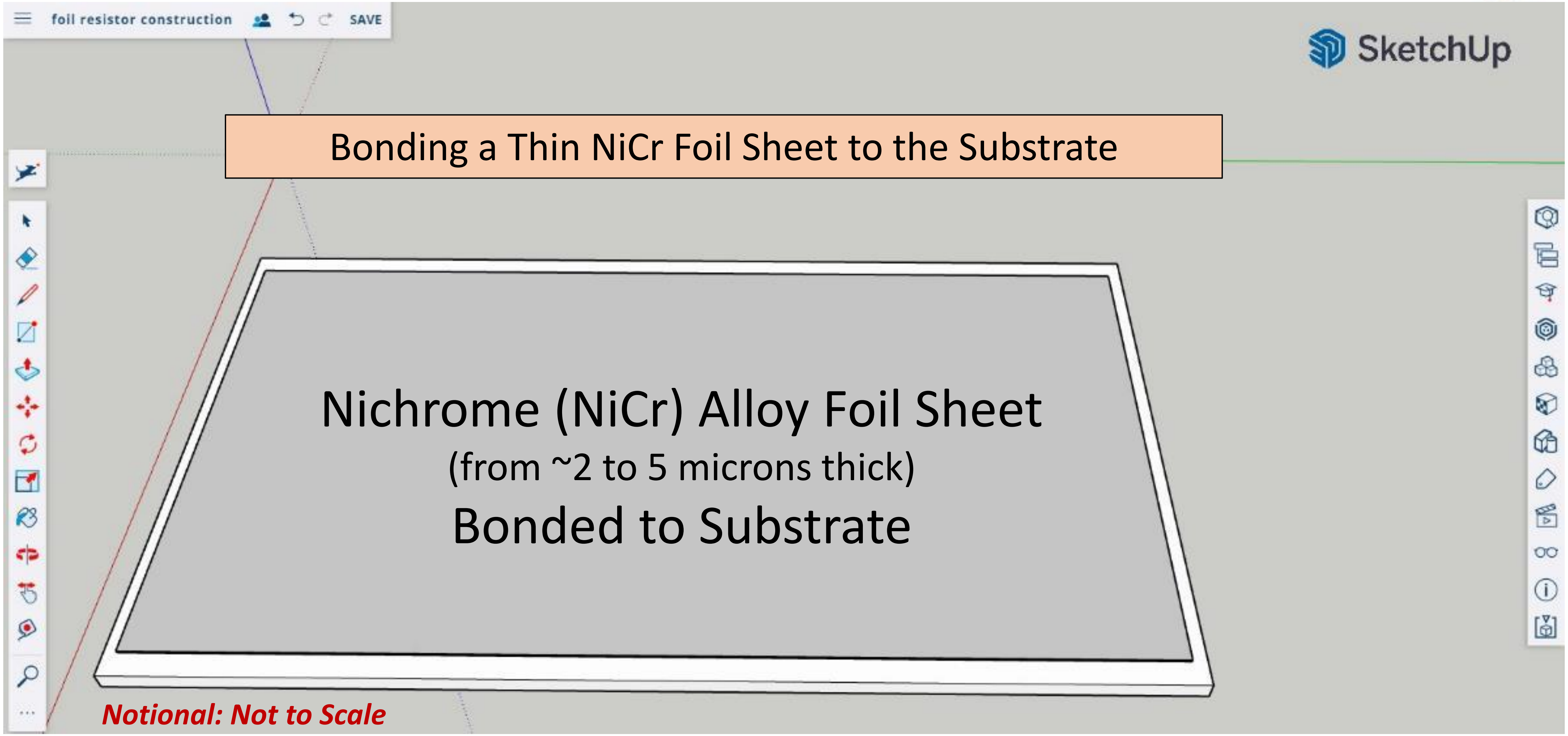


Applying an Adhesive to the Substrate

Adhesive Layer
(~5 microns thick)

Notional: Not to Scale

Primary Materials and Production Steps for Foil Resistors



Bonding a Thin NiCr Foil Sheet to the Substrate

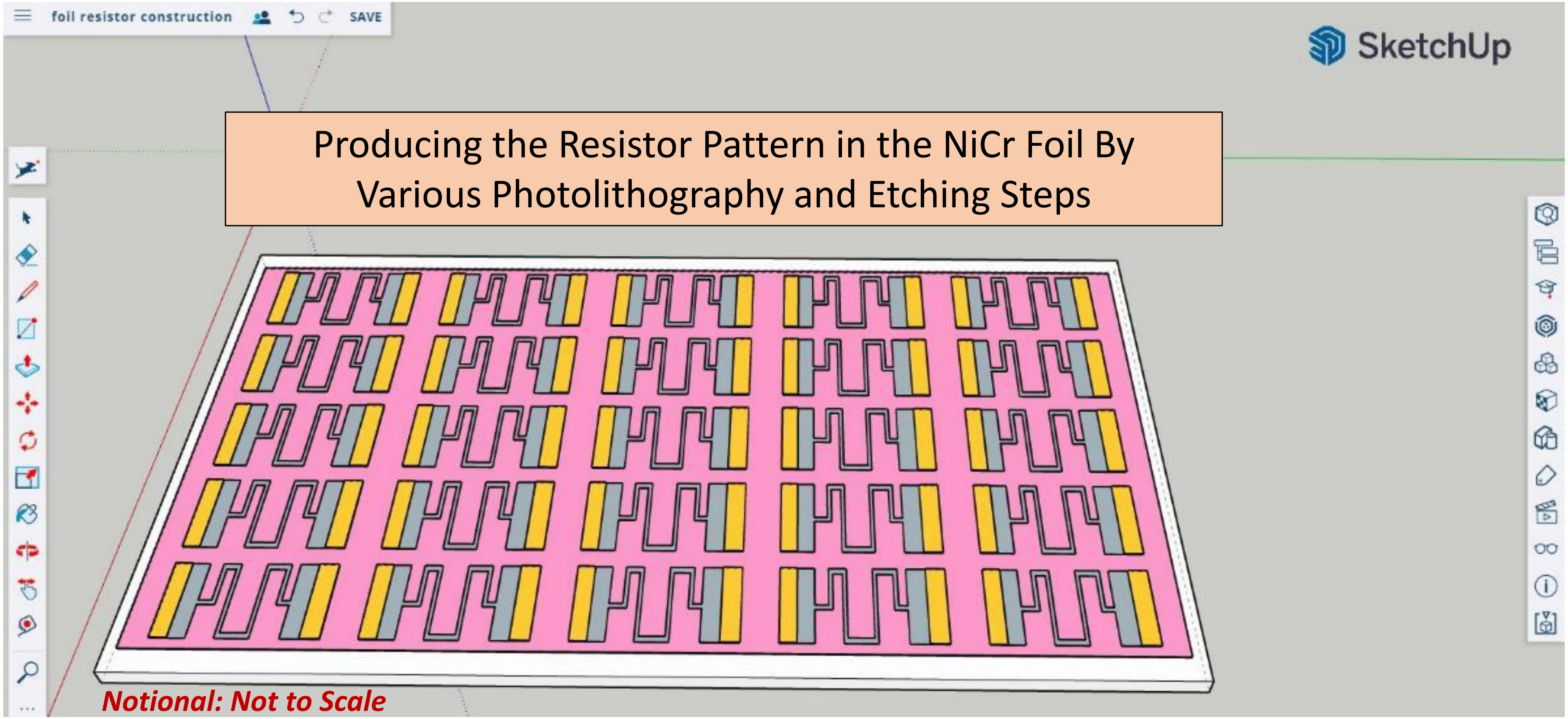
Nichrome (NiCr) Alloy Foil Sheet

(from ~2 to 5 microns thick)

Bonded to Substrate

Notional: Not to Scale

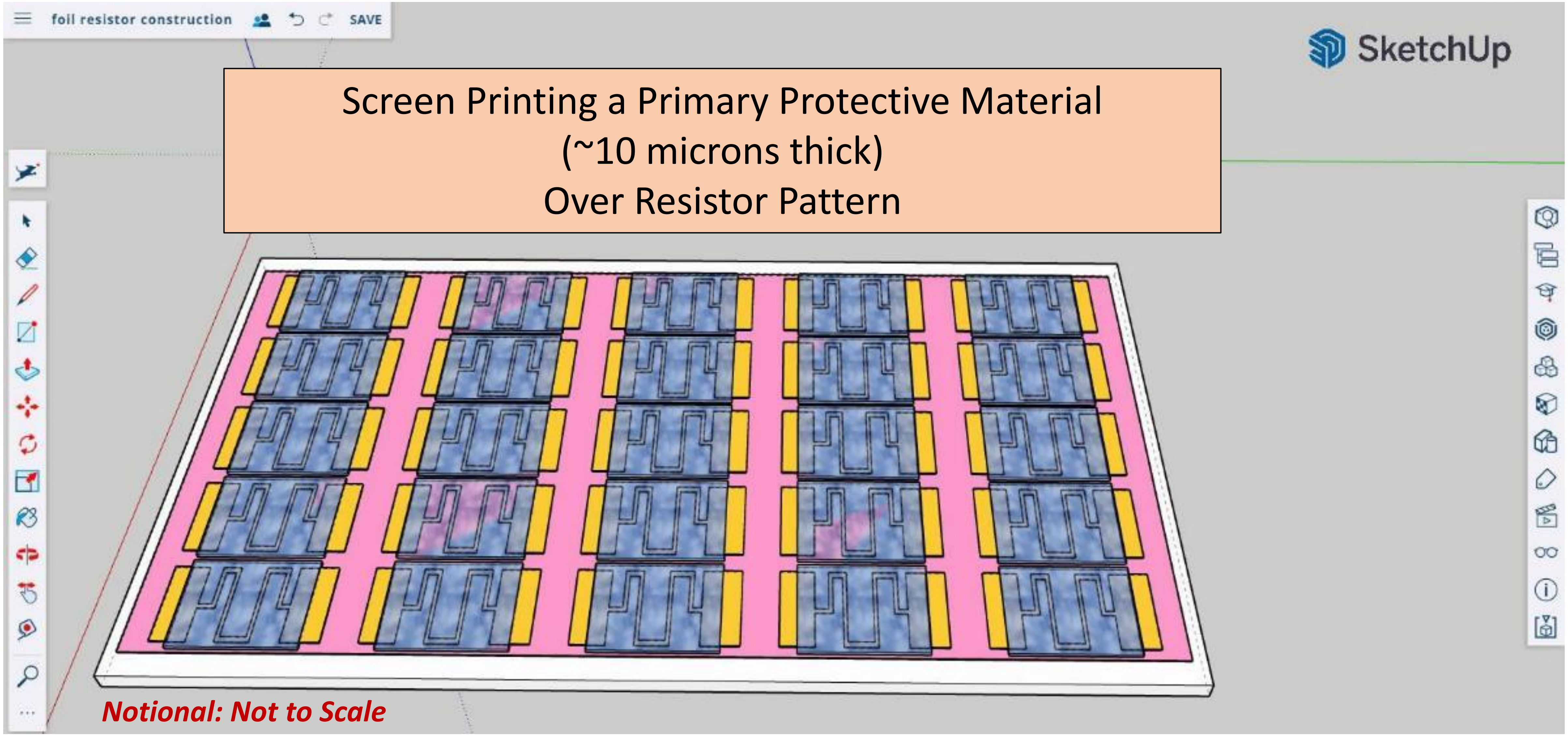
Primary Materials and Production Steps for Foil Resistors



Producing the Resistor Pattern in the NiCr Foil By Various Photolithography and Etching Steps

Notional: Not to Scale

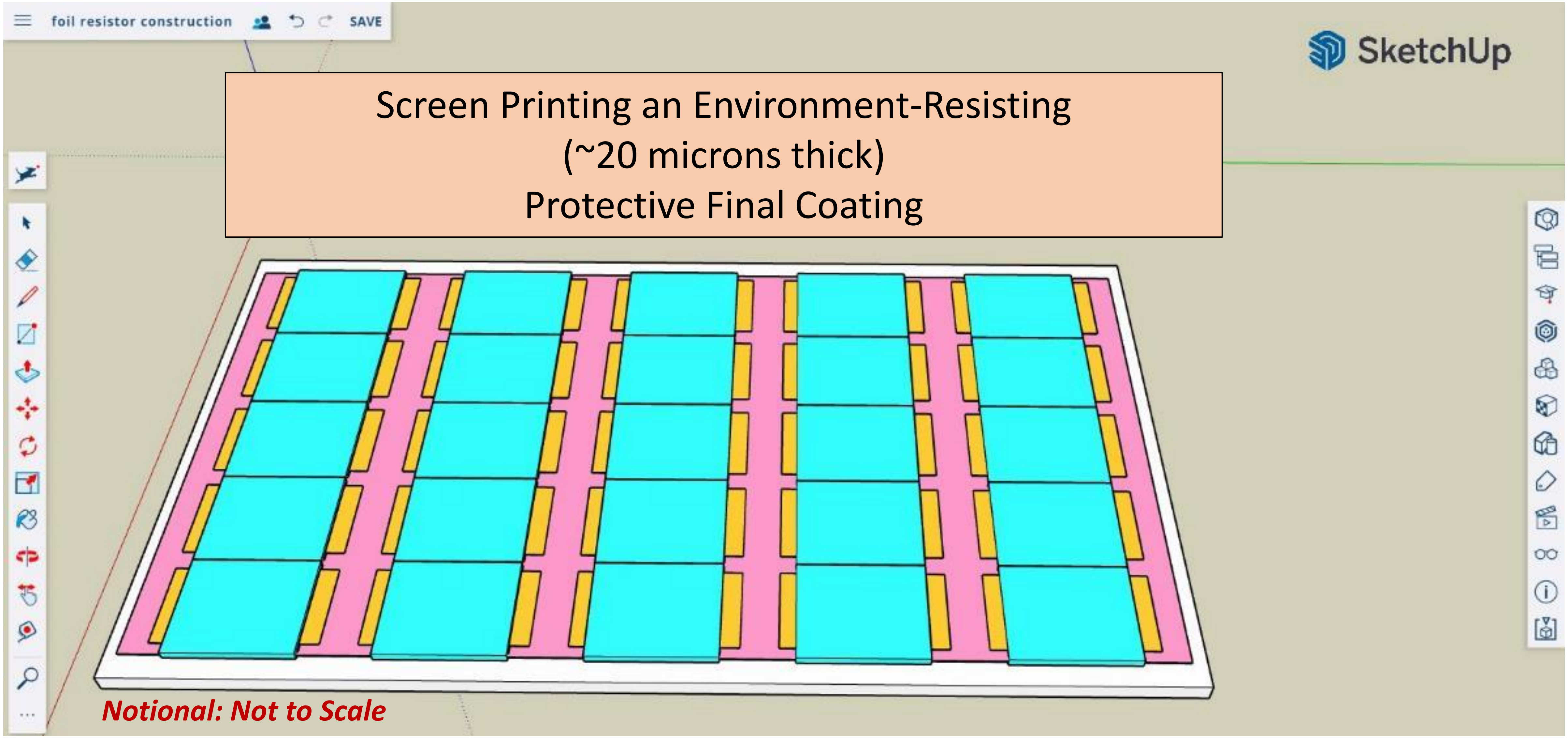
Primary Materials and Production Steps for Foil Resistors



Screen Printing a Primary Protective Material
(~10 microns thick)
Over Resistor Pattern

Notional: Not to Scale

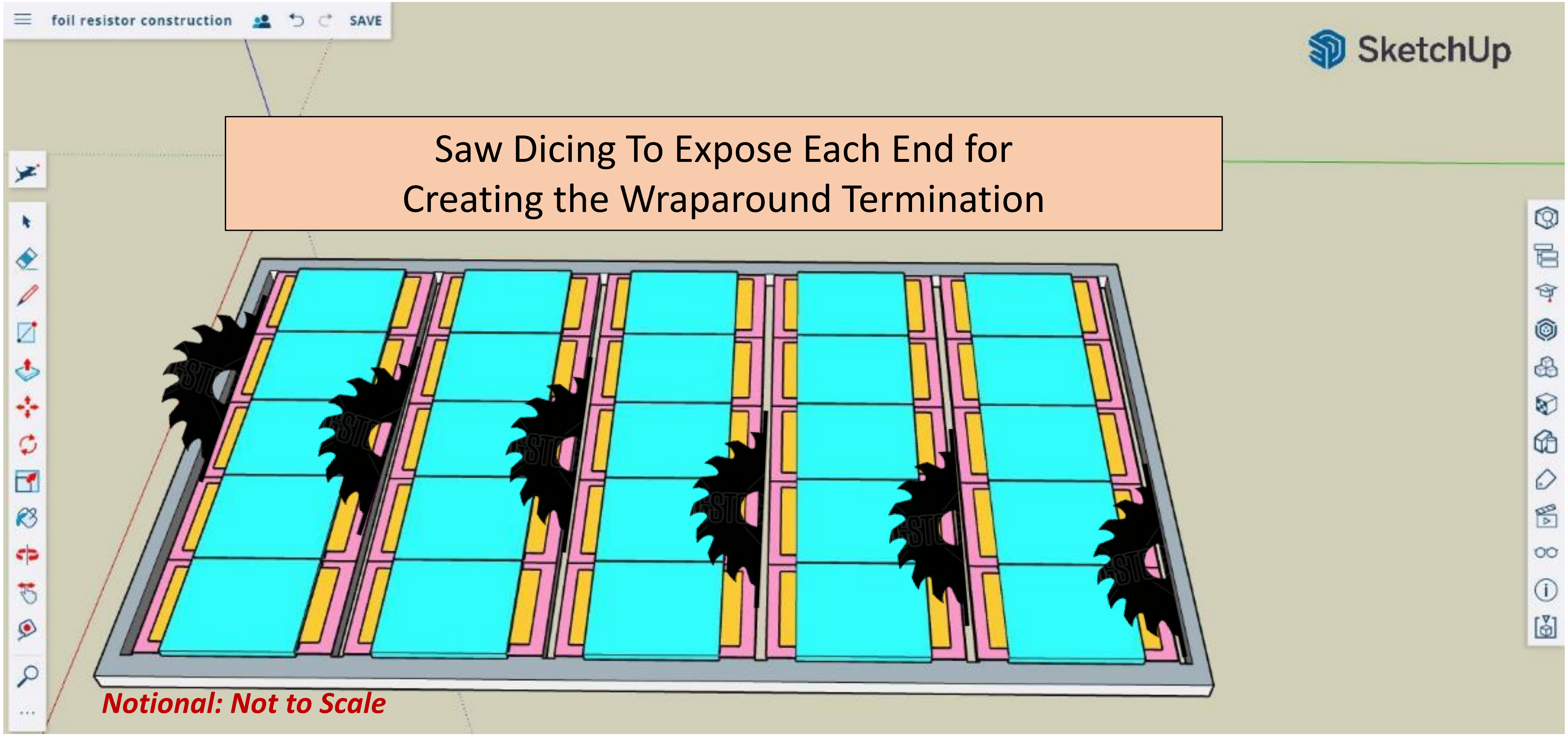
Primary Materials and Production Steps for Foil Resistors



Screen Printing an Environment-Resisting
(~20 microns thick)
Protective Final Coating

Notional: Not to Scale

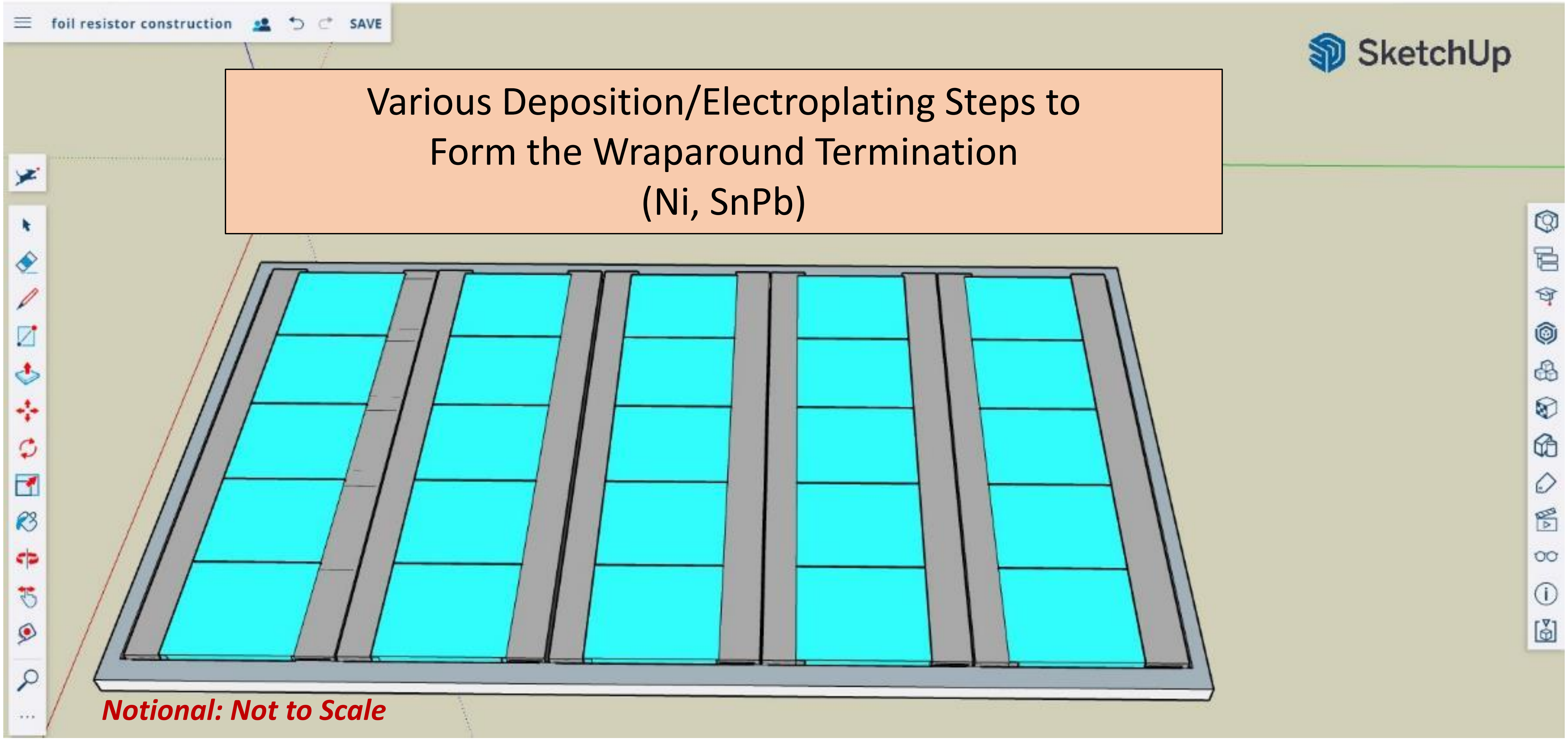
Primary Materials and Production Steps for Foil Resistors



Saw Dicing To Expose Each End for Creating the Wraparound Termination

Notional: Not to Scale

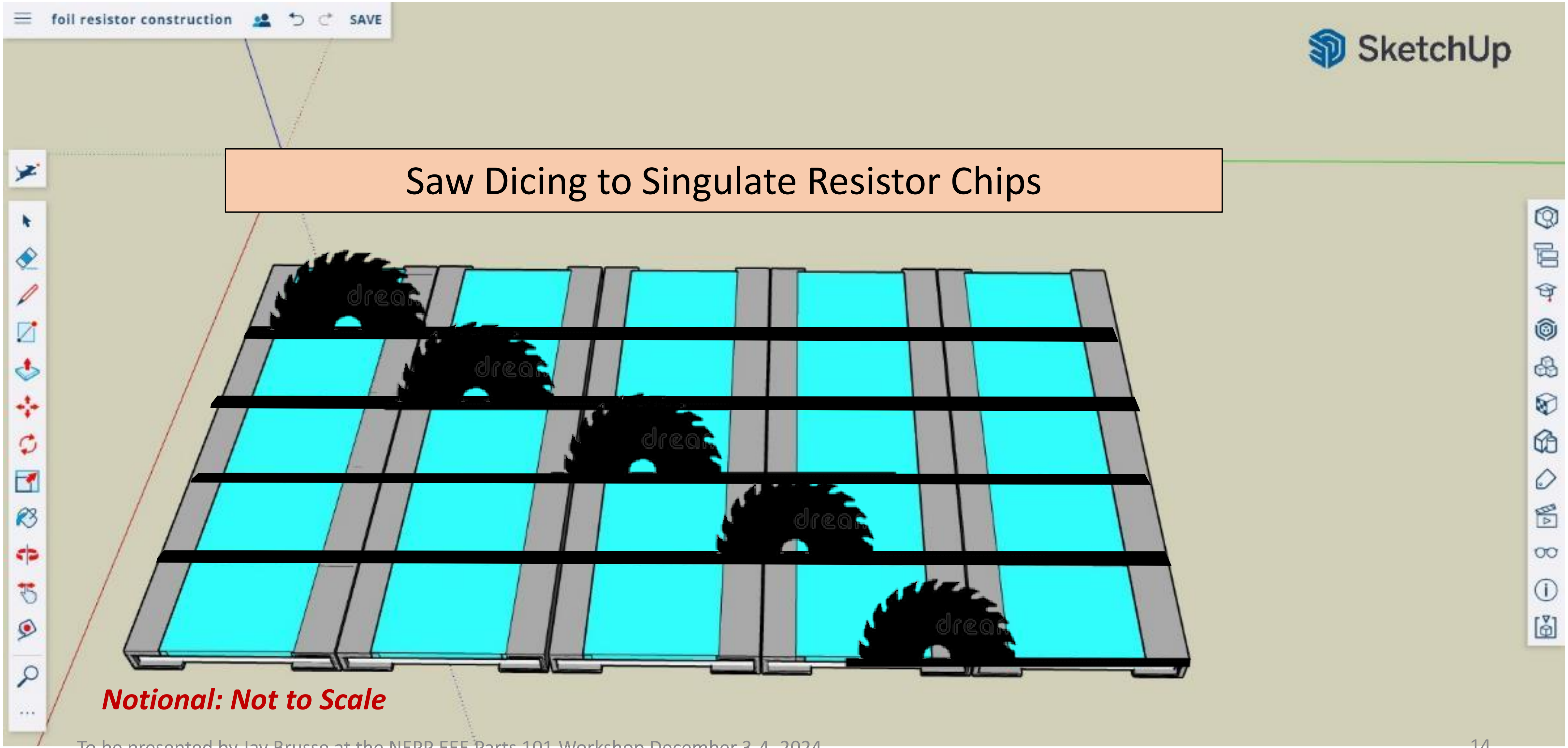
Primary Materials and Production Steps for Foil Resistors



Various Deposition/Electroplating Steps to Form the Wraparound Termination (Ni, SnPb)

Notional: Not to Scale

Primary Materials and Production Steps for Foil Resistors



Saw Dicing to Singulate Resistor Chips

Notional: Not to Scale

Foil Resistor Gridline Patterns

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

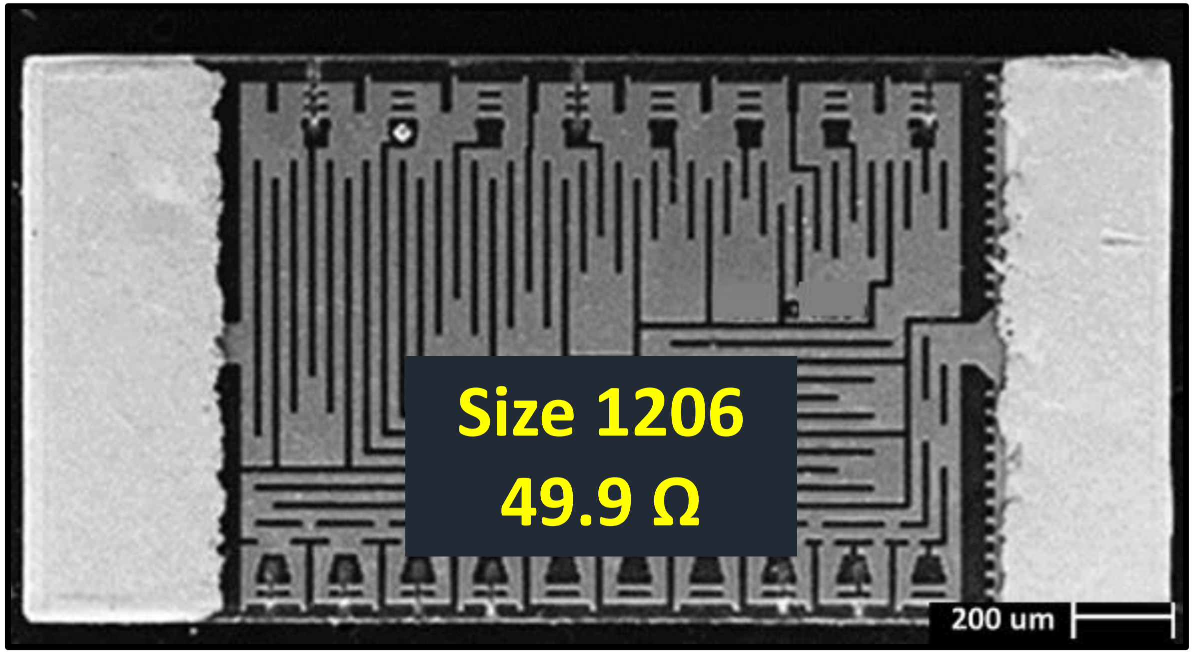
R = Resistance (Ω)
ρ = Resistivity of Foil
L = Length of Resistor Element
A = Cross Sectional Area of Gridline
*(i.e., thickness * width)*

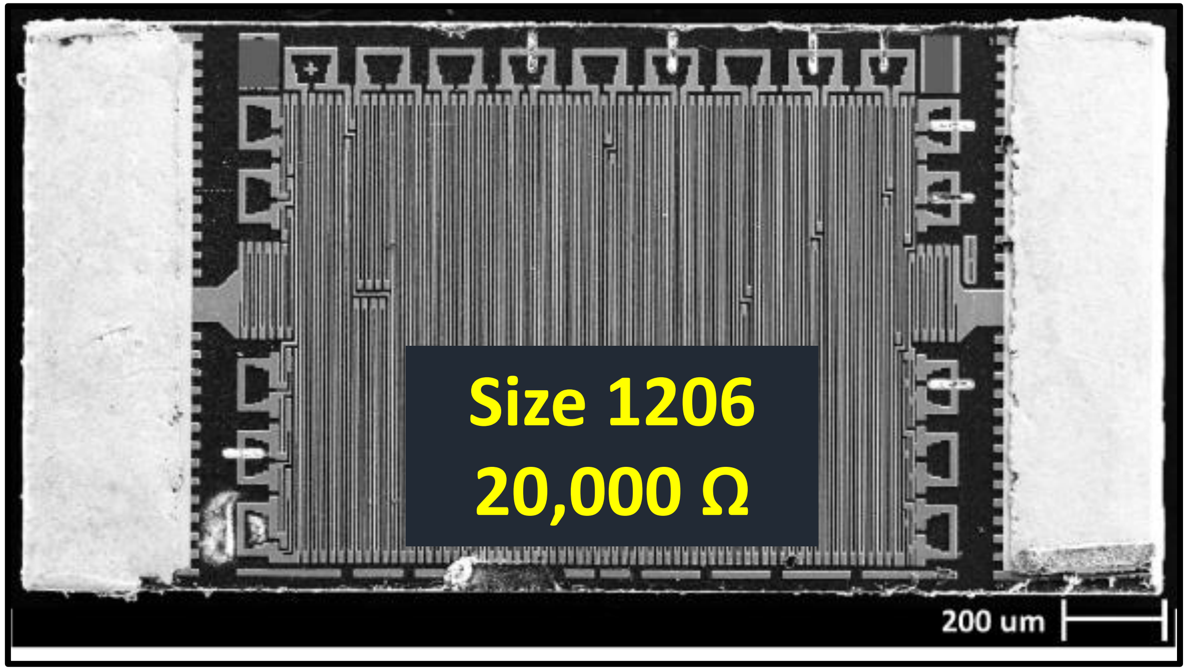
Low Resistance Values

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*

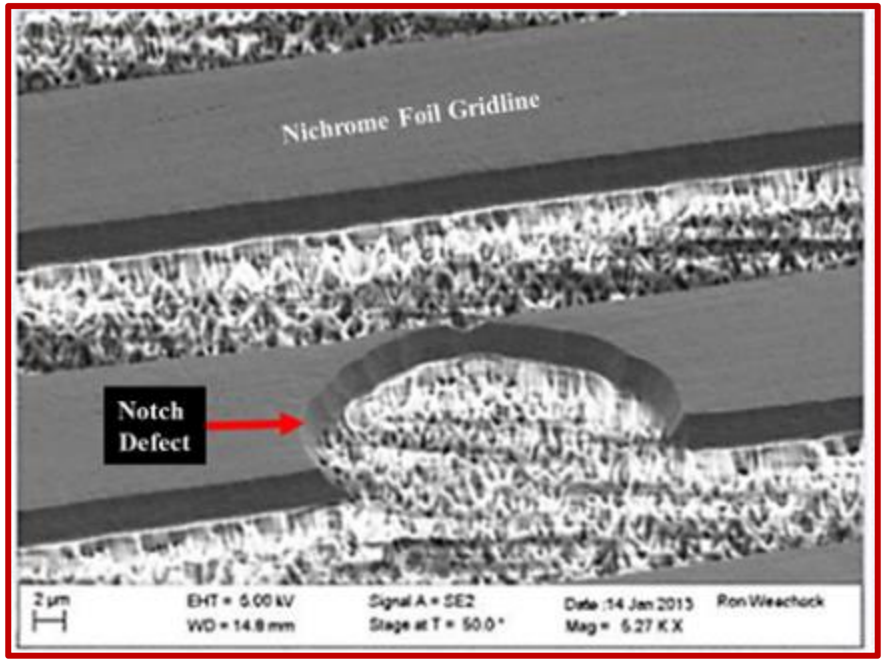




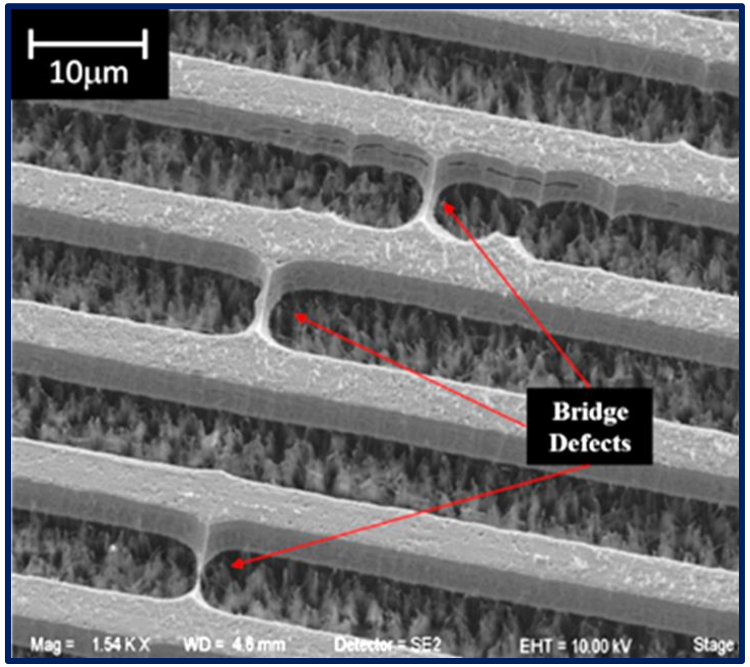
To be presented by Jay Brusse at the NEPP EEE Parts 101 Workshop December 3-4, 2024.

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

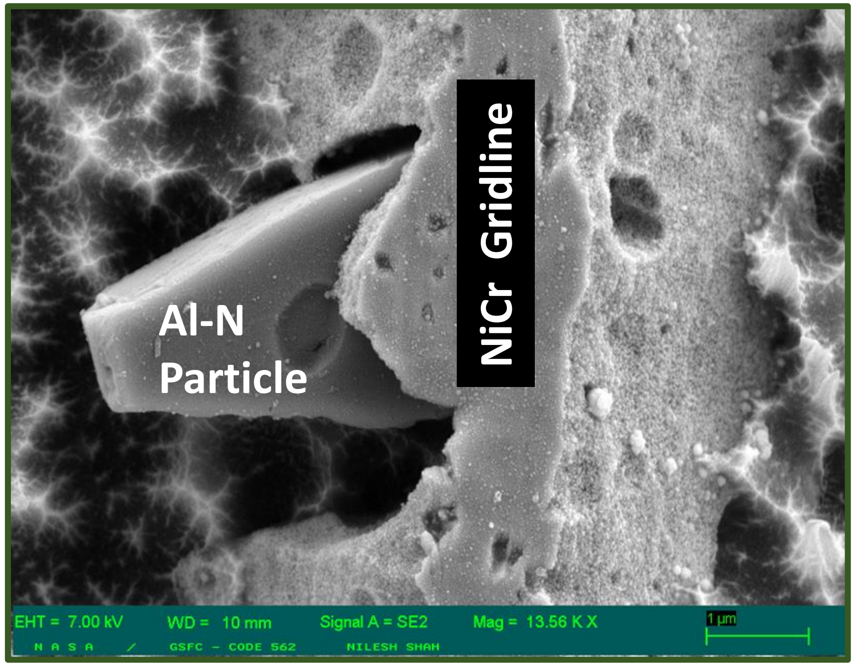
Notches



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

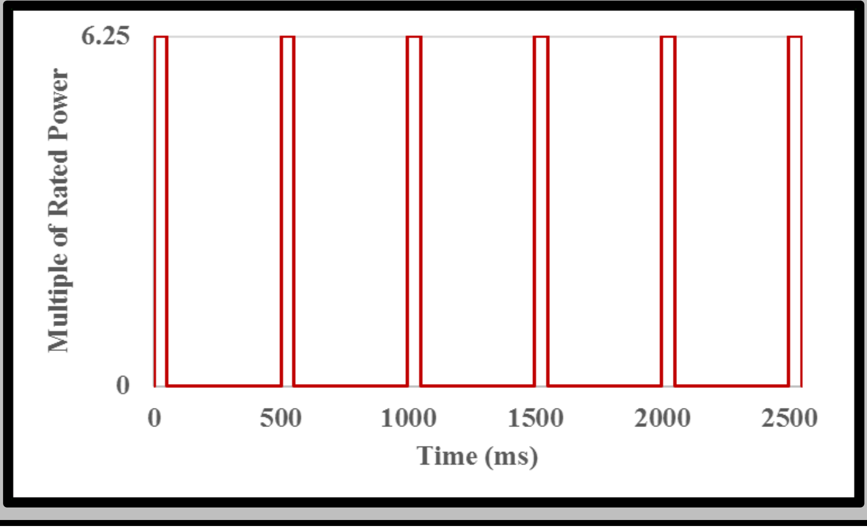
Test Method	Test Conditions	Rejection Criteria
Pre-Encapsulation Optical Microscopy	**30x to 60x Magnification**	**Notches > 75% nominal line width** **Bridges < 10% smallest line width**
Short Time Overload (STOL)	**6.25x Rated Power For 5 Seconds**	**ΔR > 0.02%**
Power Conditioning	**1x to 1.5x Rated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

Hot Spots! A New Screening Method to Detect Localized Constrictions

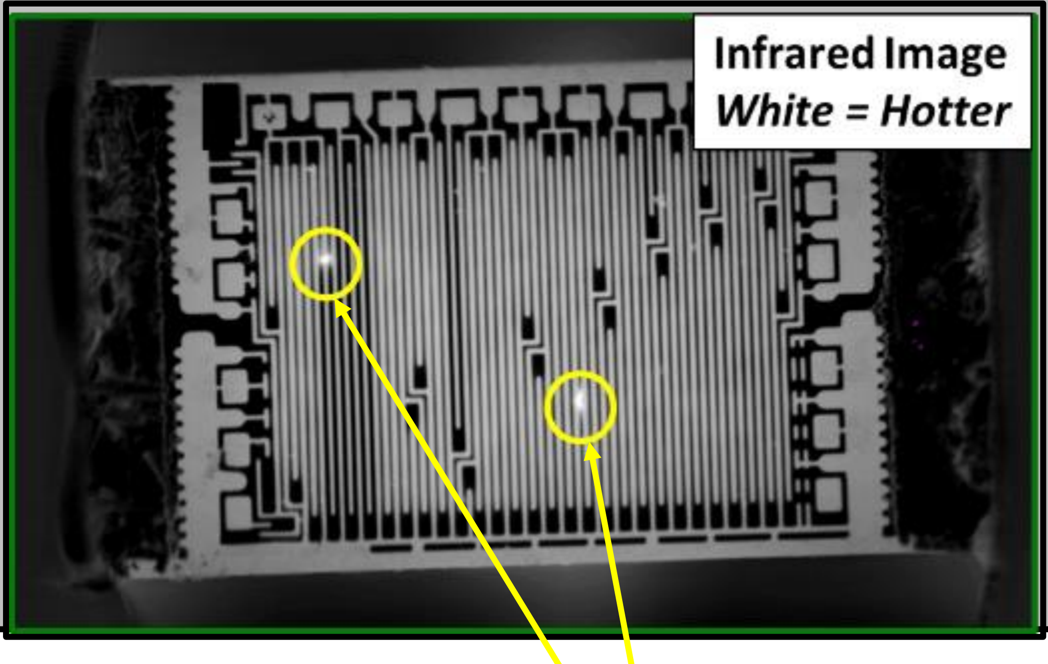
Pulsed-Power Combined with High Resolution Infrared Imaging

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"*

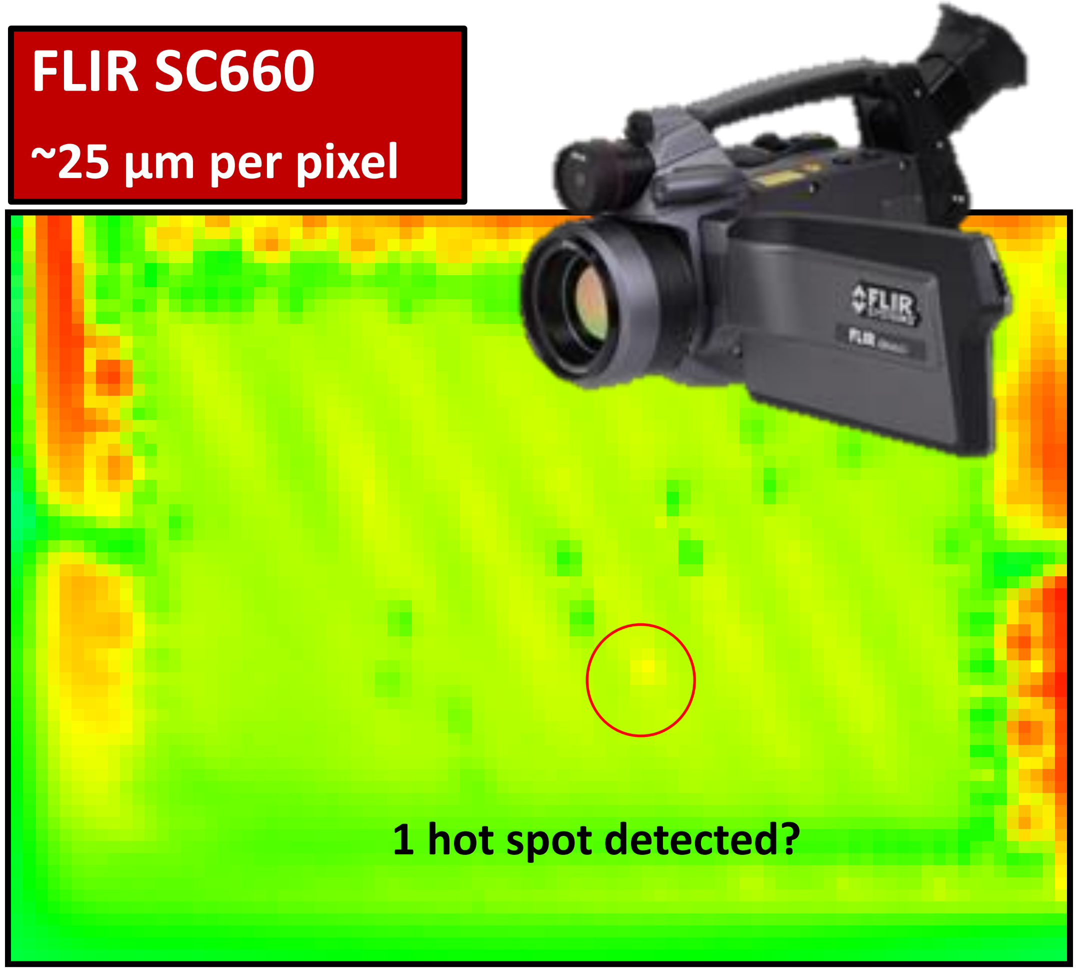
- Hot spots are indicative of constriction defects (e.g., notches, bridges, embedded particles)

Comparison of Two Different Infrared Cameras

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

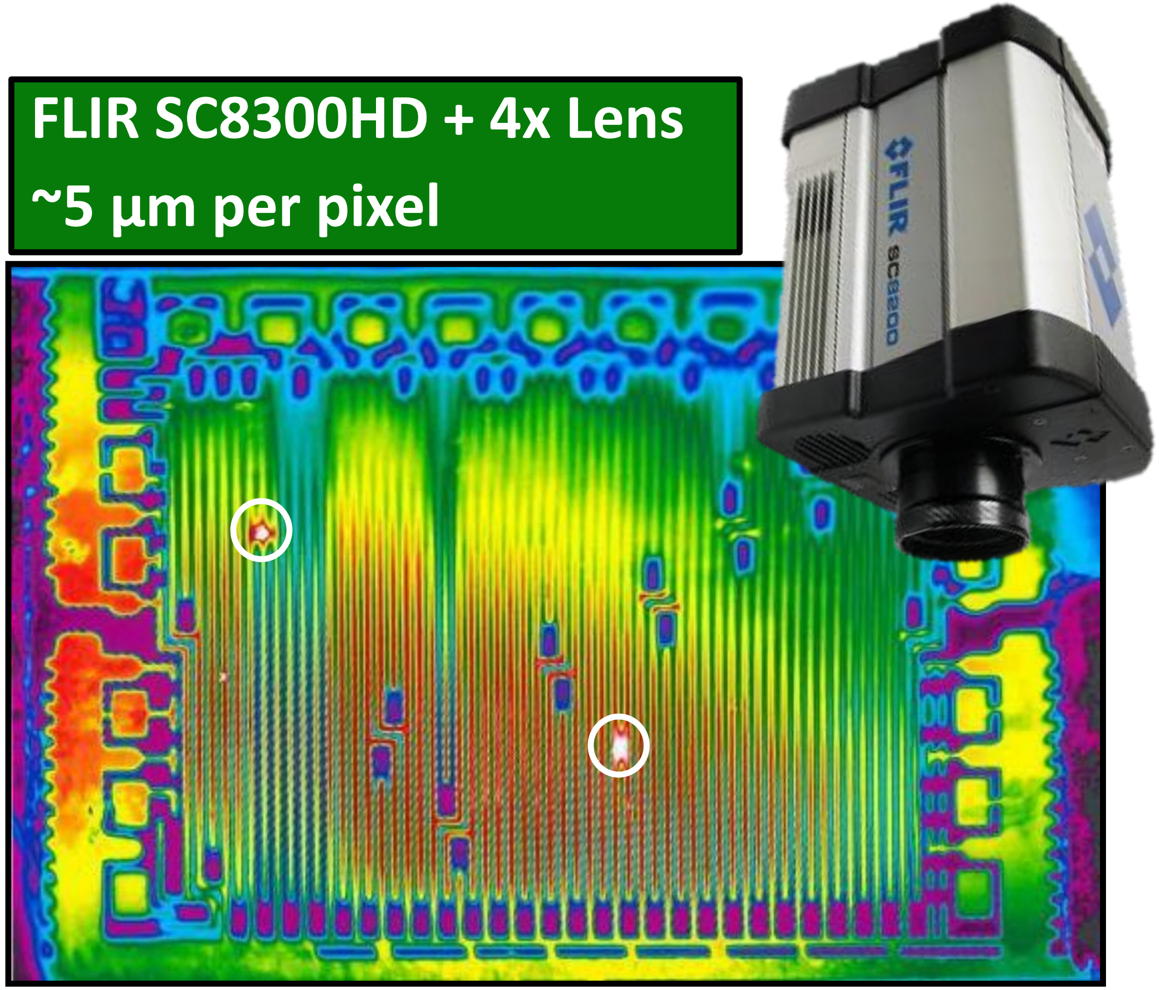
FLIR SC660

~25 µm per pixel



FLIR SC8300HD + 4x Lens

~5 µm per pixel

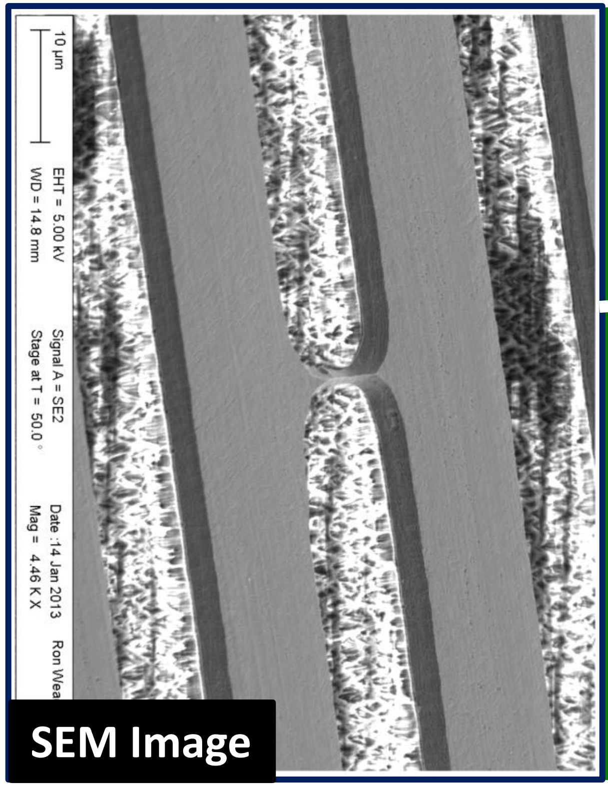


Demonstration of New Screening Method

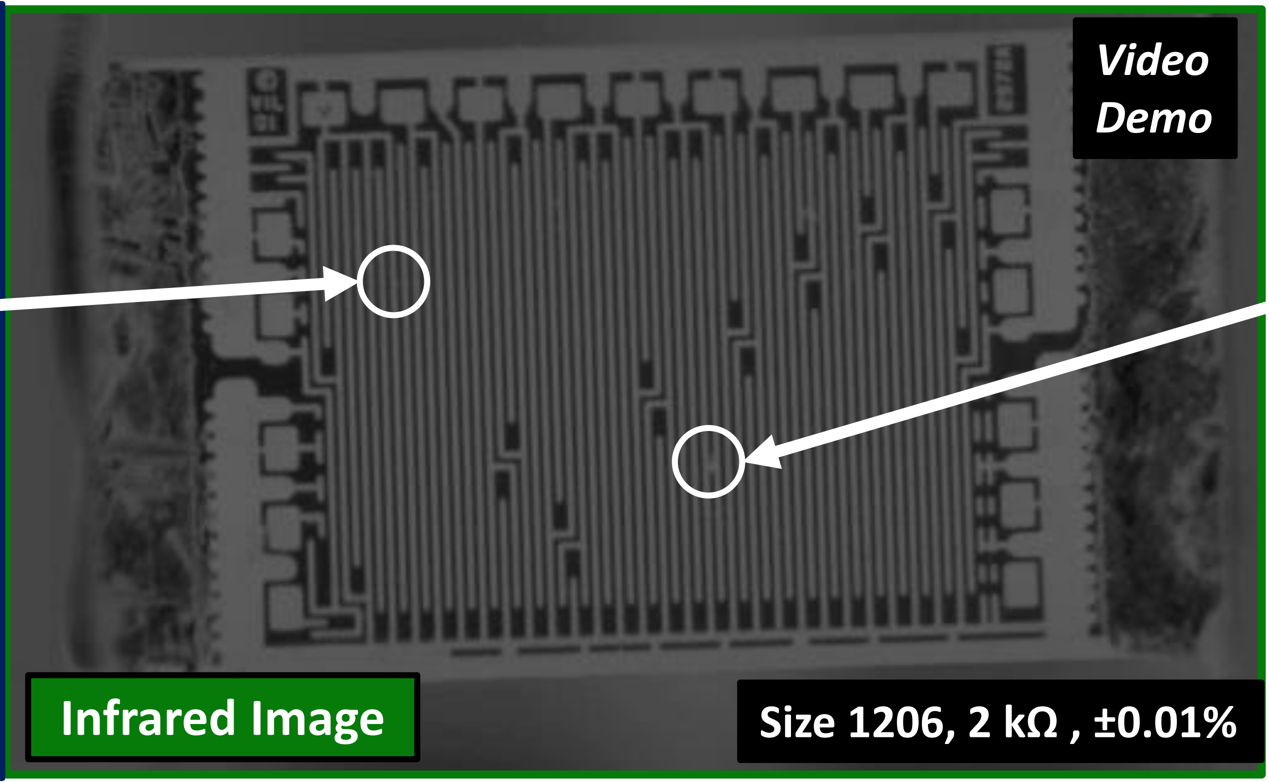
Using DPA Sample with Bridge and Notch Defects

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

Bridge Defect



SEM Image

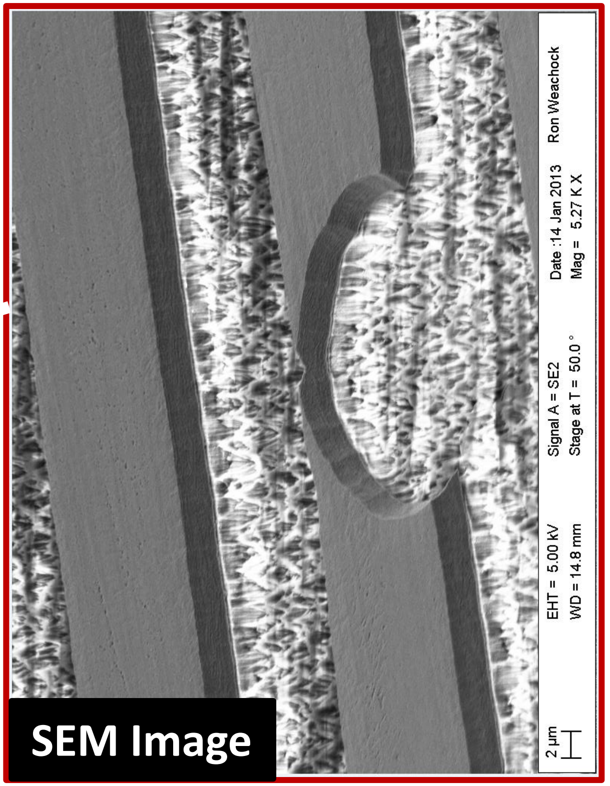


Video Demo

Infrared Image

Size 1206, 2 kΩ , ±0.01%

Notch Defect



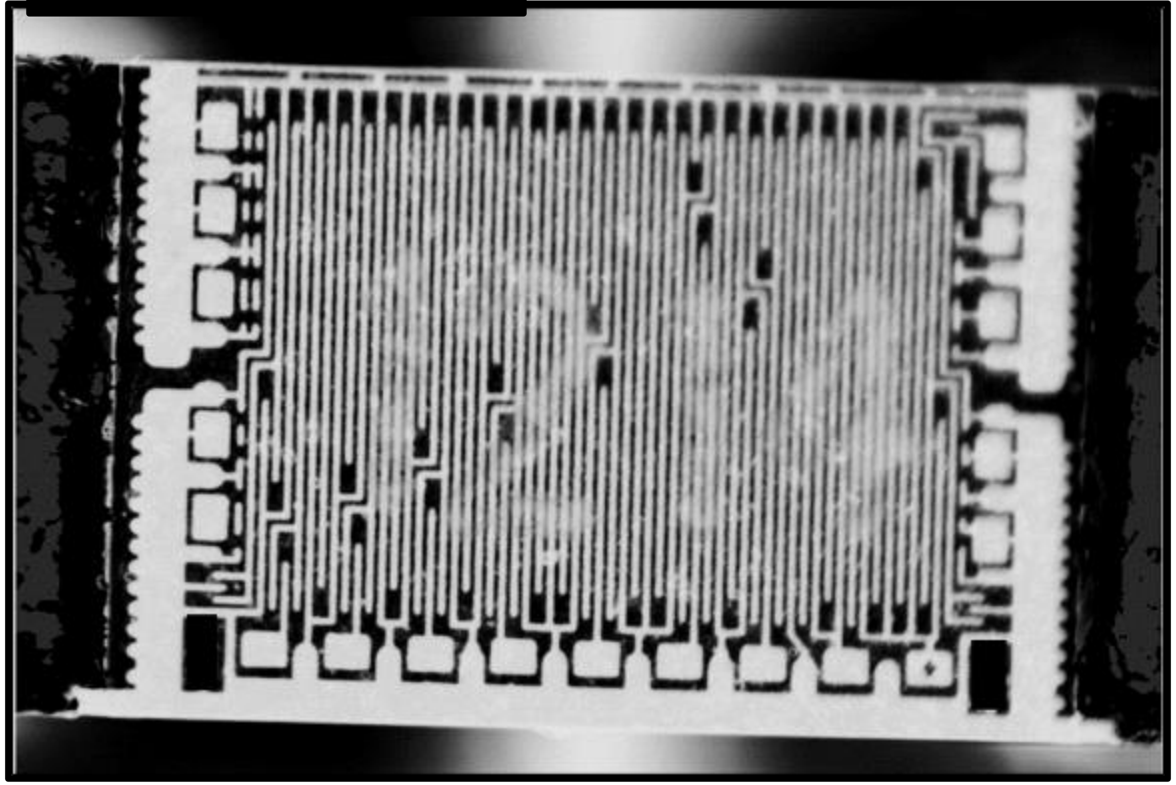
SEM Image

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

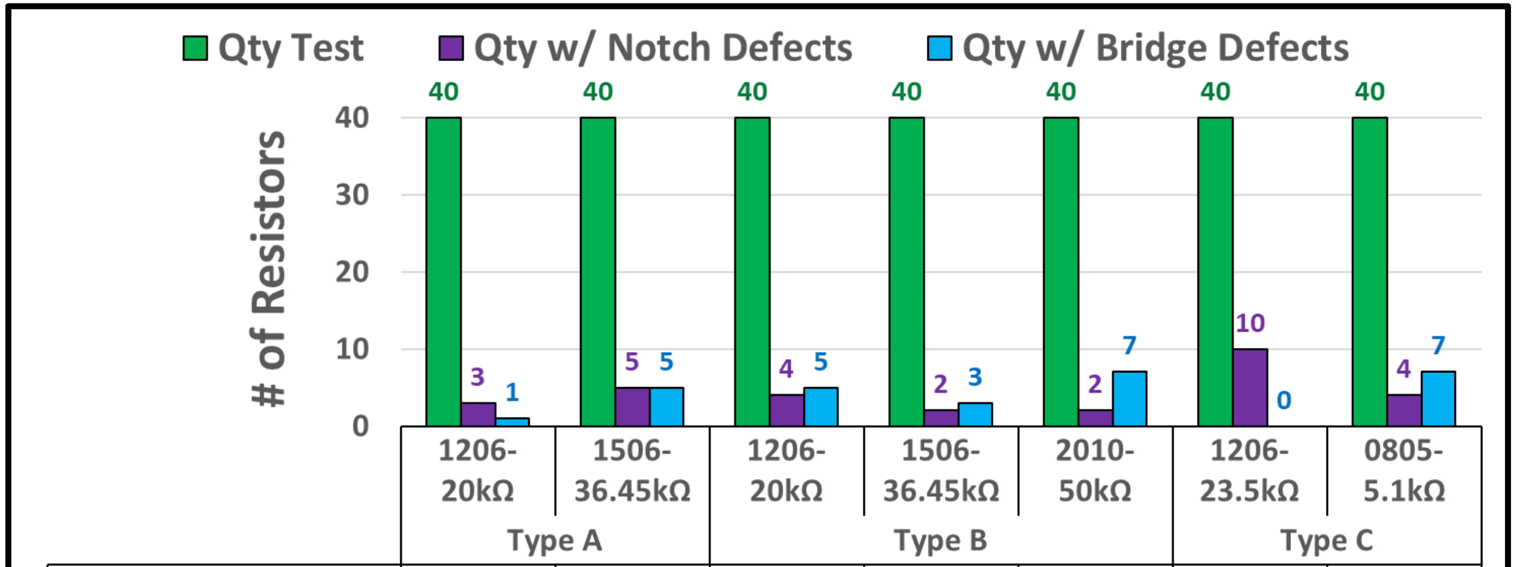
Foil Resistors Used for Evaluation

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)

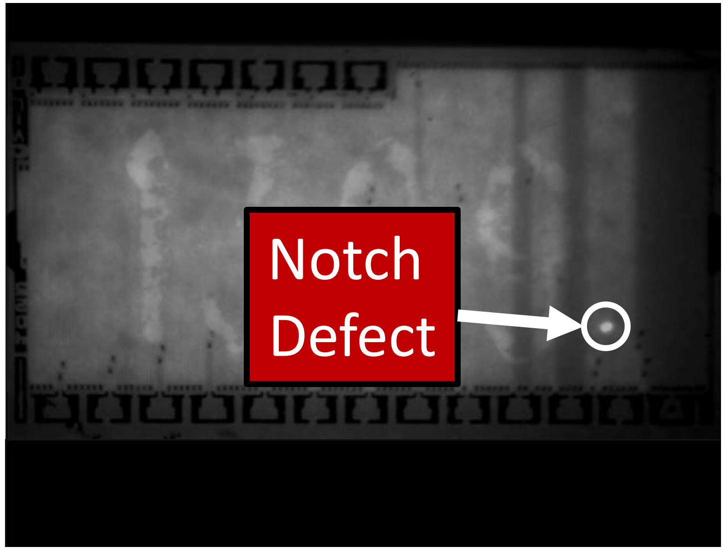
Results: Pre-Life Test Pulsed-Power Infrared Screening

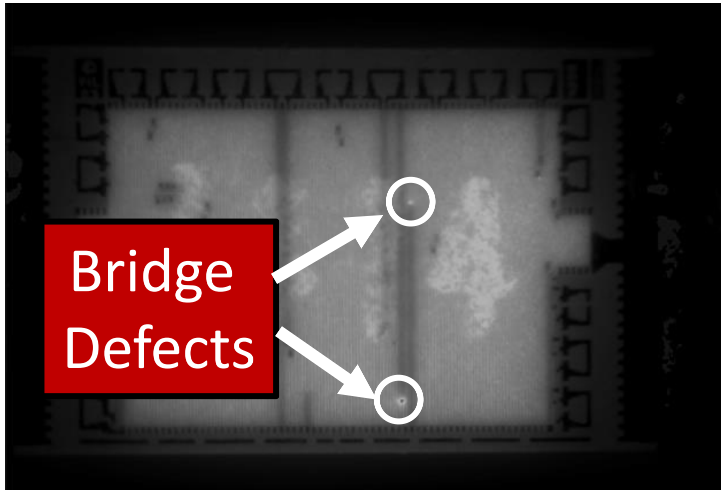
~10% to 25% of Resistors Per Lot Tested Had Constriction Defects



	1206-20kΩ	1506-36.45kΩ	1206-20kΩ	1506-36.45kΩ	2010-50kΩ	1206-23.5kΩ	0805-5.1kΩ
	Type A		Type B			Type C	
🟩 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

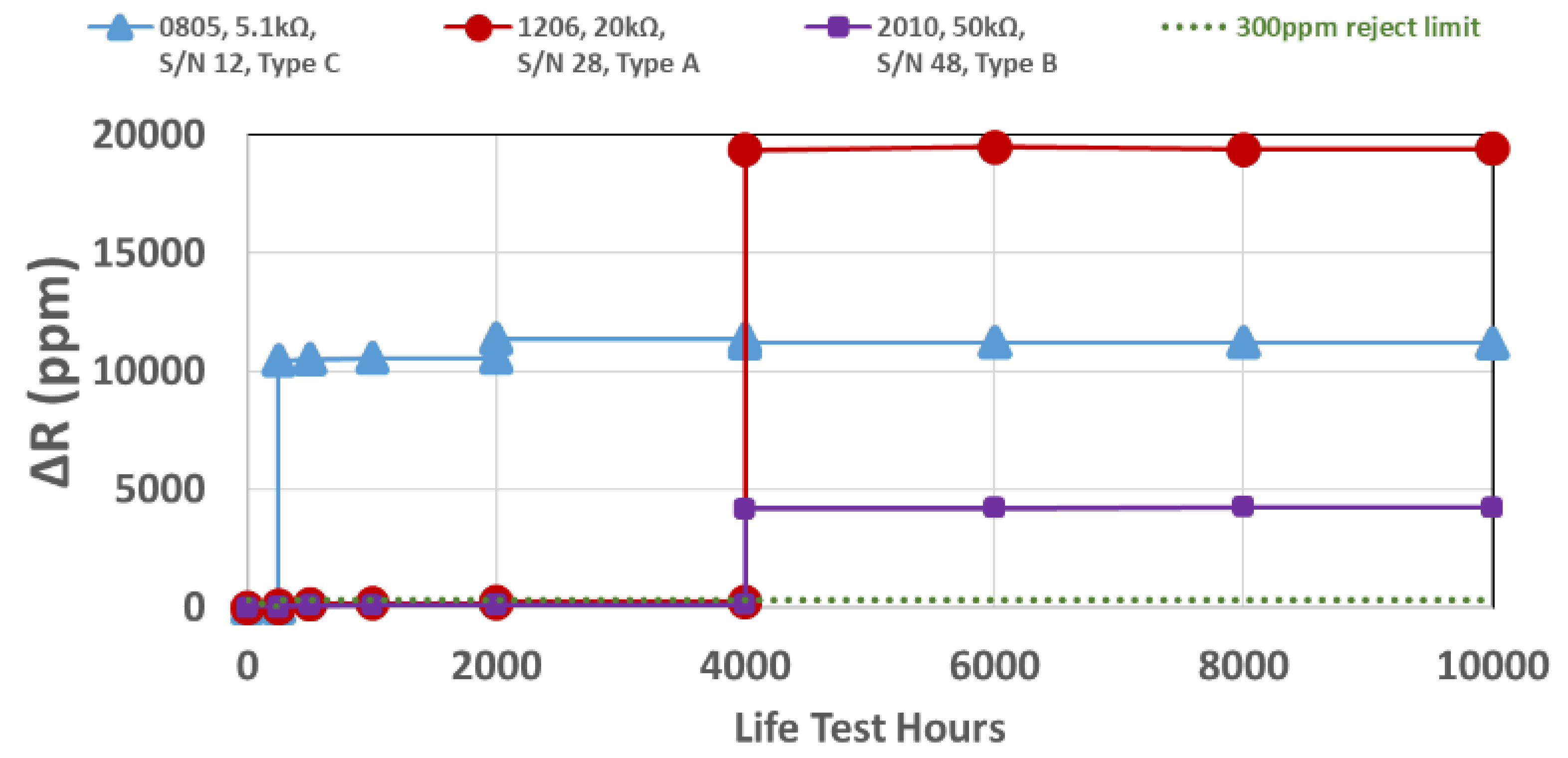
Totals
280 Tested
30 with Notch Defects
28 with Bridge Defects

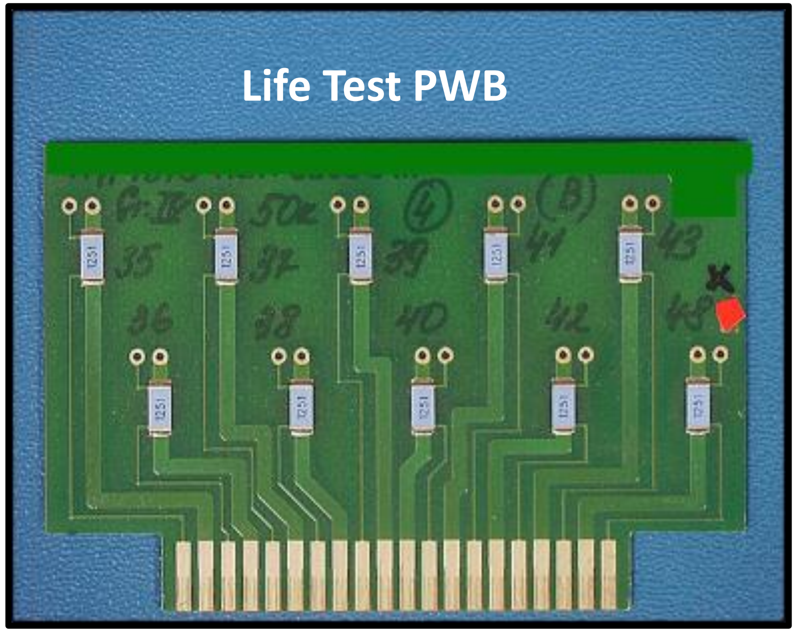

Notch Defect


Bridge Defects

Results: 3 Life Test Failures (280 Resistors Tested)

Abrupt Positive Resistance Shift Failure Modes





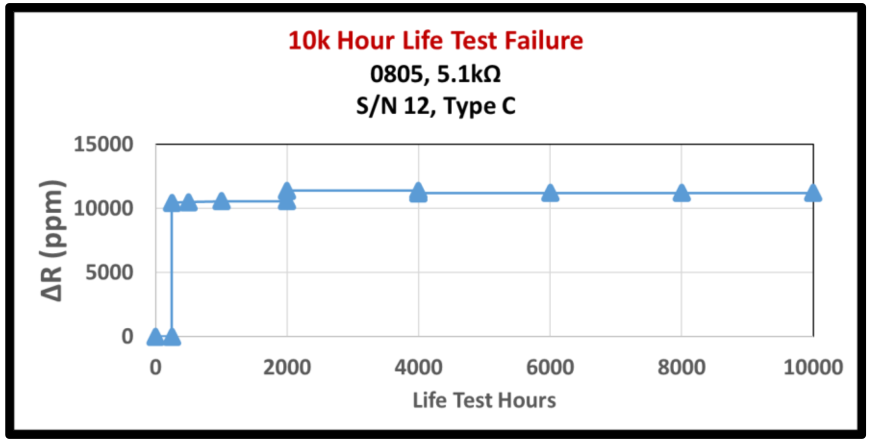
Life Test PWB

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

To be presented by Jay Brusse at the NEPP EEE Parts 101 Workshop December 3-4, 2024.

Failure Analysis:

0805, 5.1kΩ, S/N 12, Type "C"

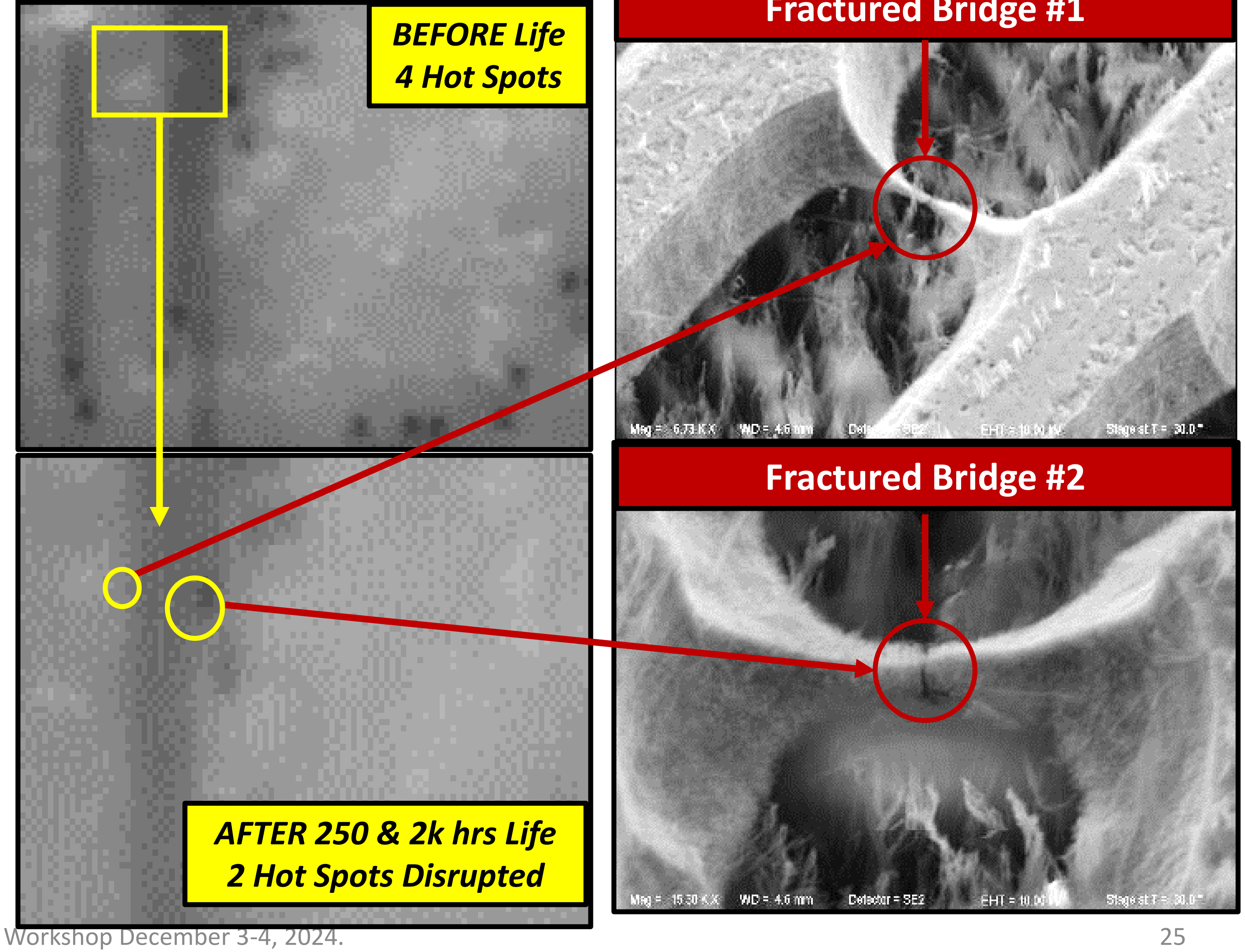


Conclusion:

***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

Pulsed-Power Infrared Screen



BEFORE Life 4 Hot Spots

AFTER 250 & 2k hrs Life 2 Hot Spots Disrupted

Fractured Bridge #1

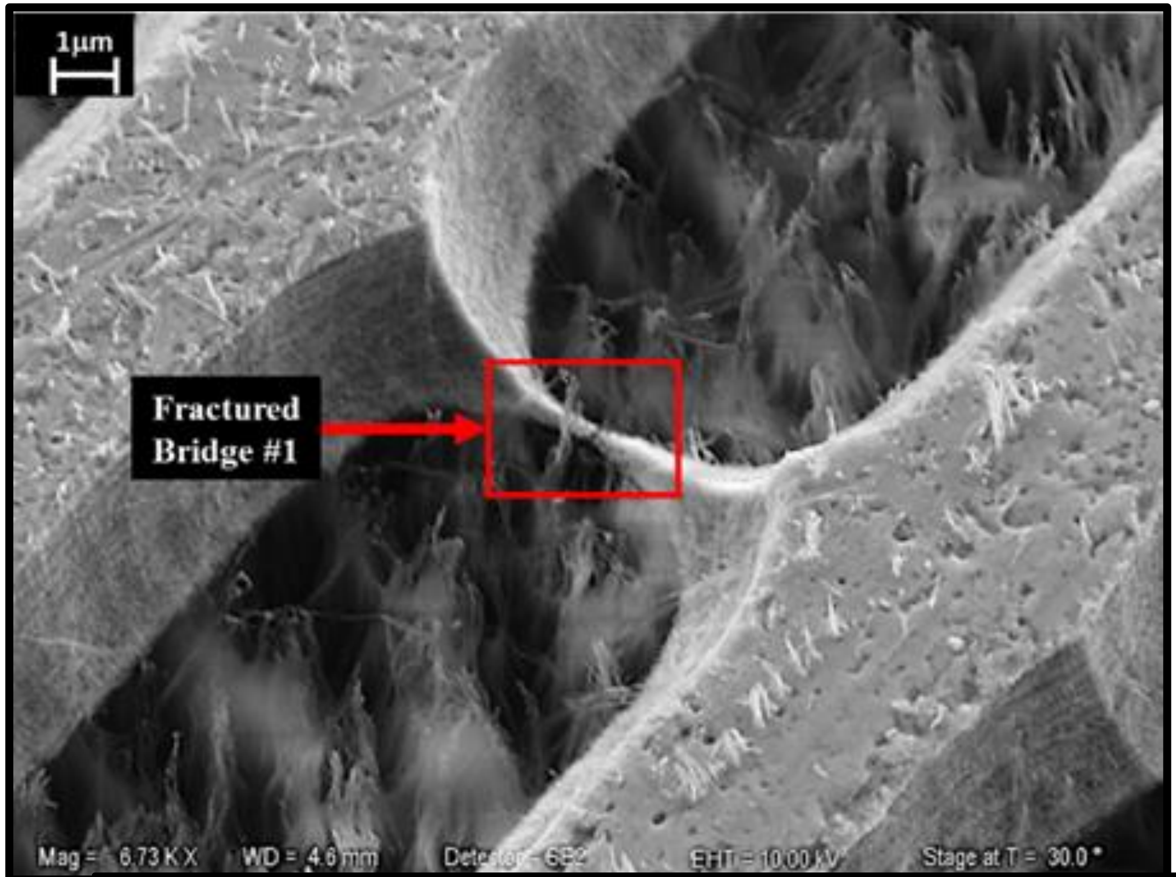
Fractured Bridge #2

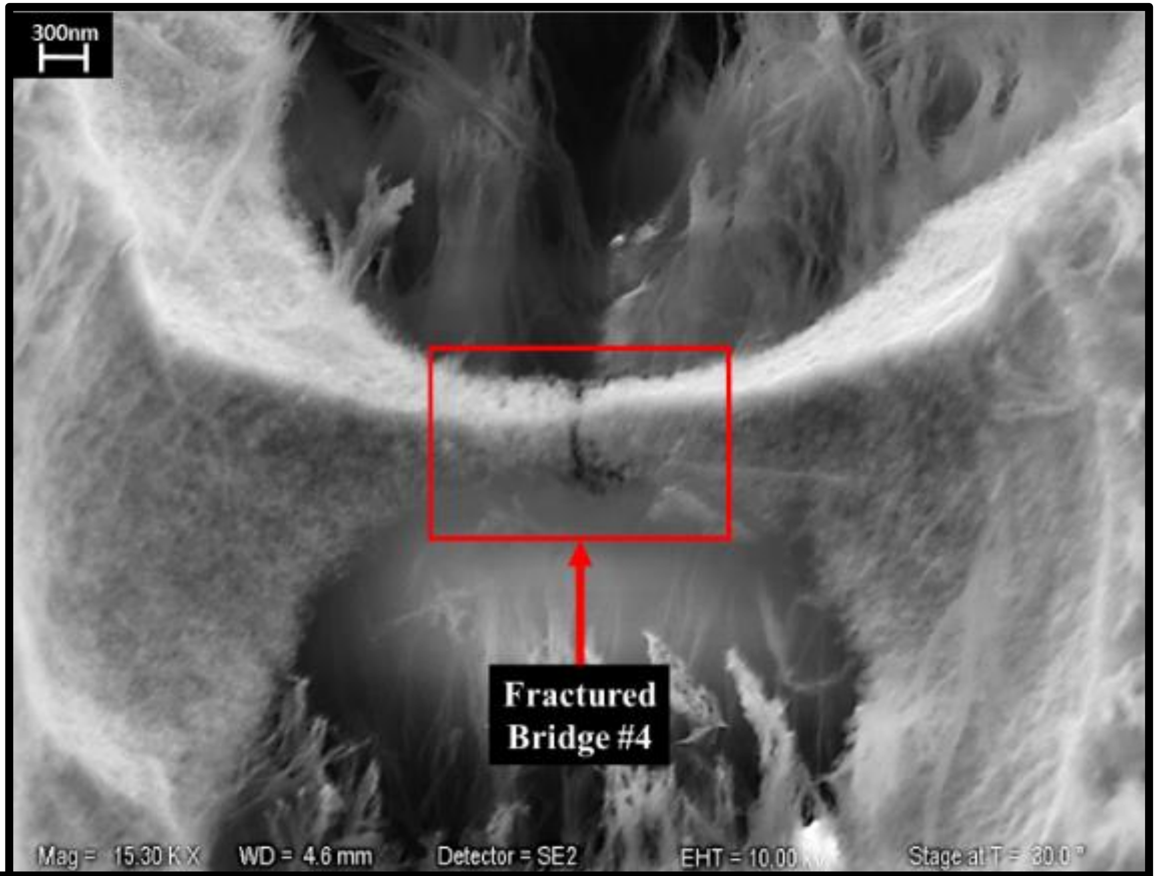
Failure Analysis

0805, 5.1kΩ, S/N 12, Type “C”

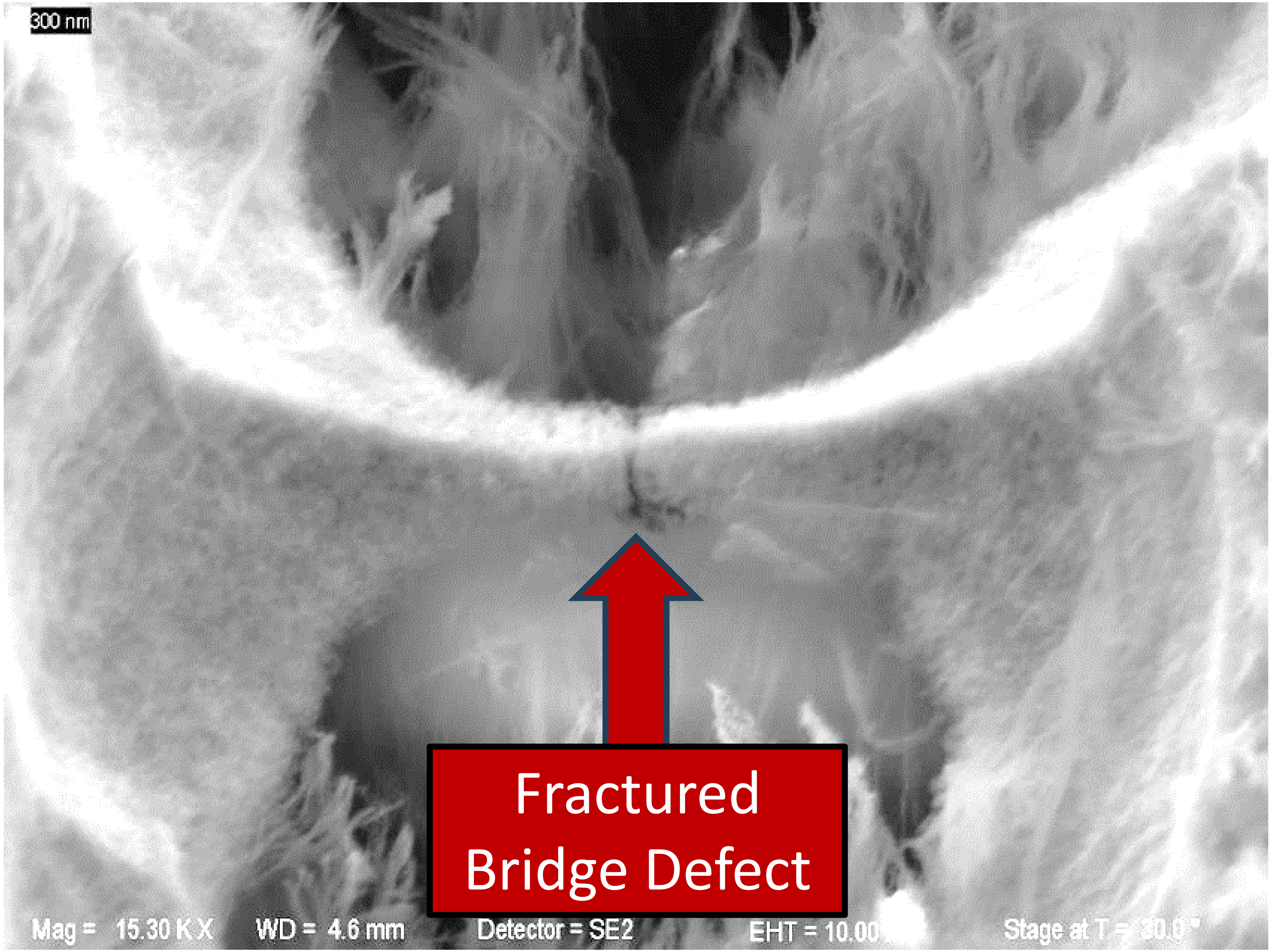
Two Positive Resistance Shifts During Life Test

ΔR1 = +10440ppm @ 250 hrs; ΔR2 = +815ppm @ 2000 hrs





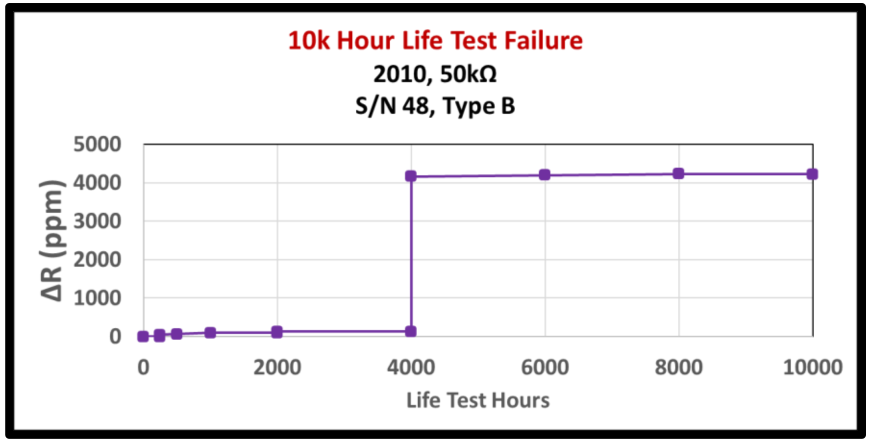
Conclusion:
This Resistor Exhibited Two Abrupt Positive ΔR Shifts During Life Test.
Both Shifts Were Caused by Thermomechanically-Induced Fatigue Fracture of Two Separate Foil Bridge Defects



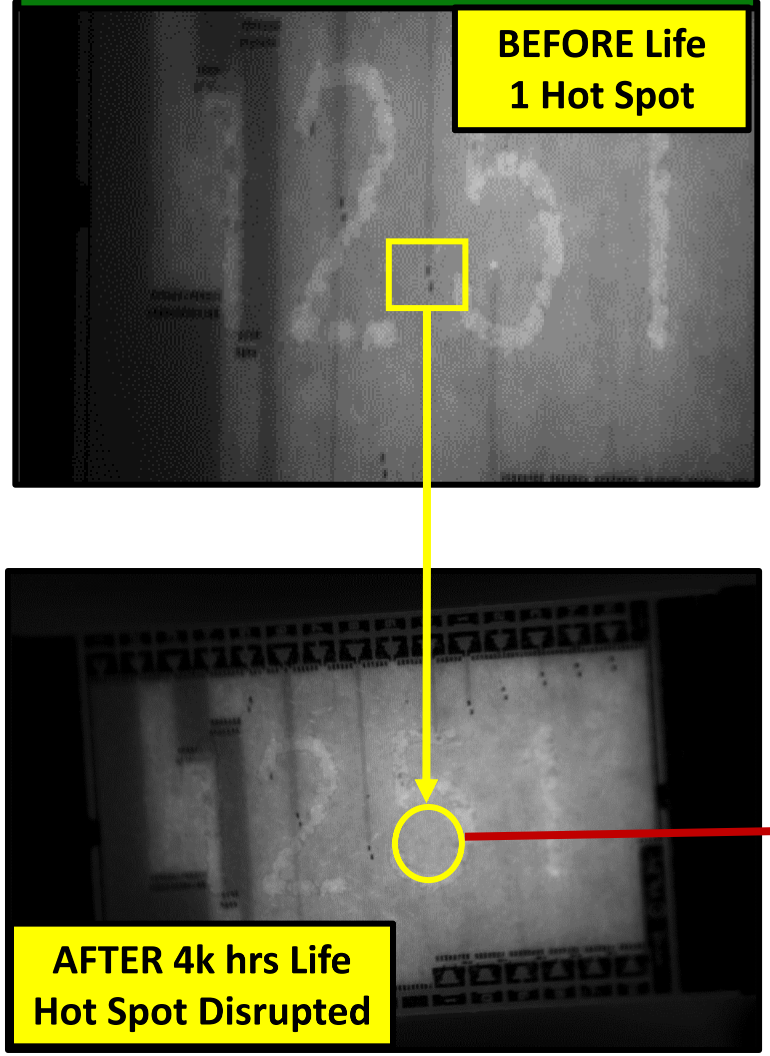
Fractured
Bridge Defect

Failure Analysis:

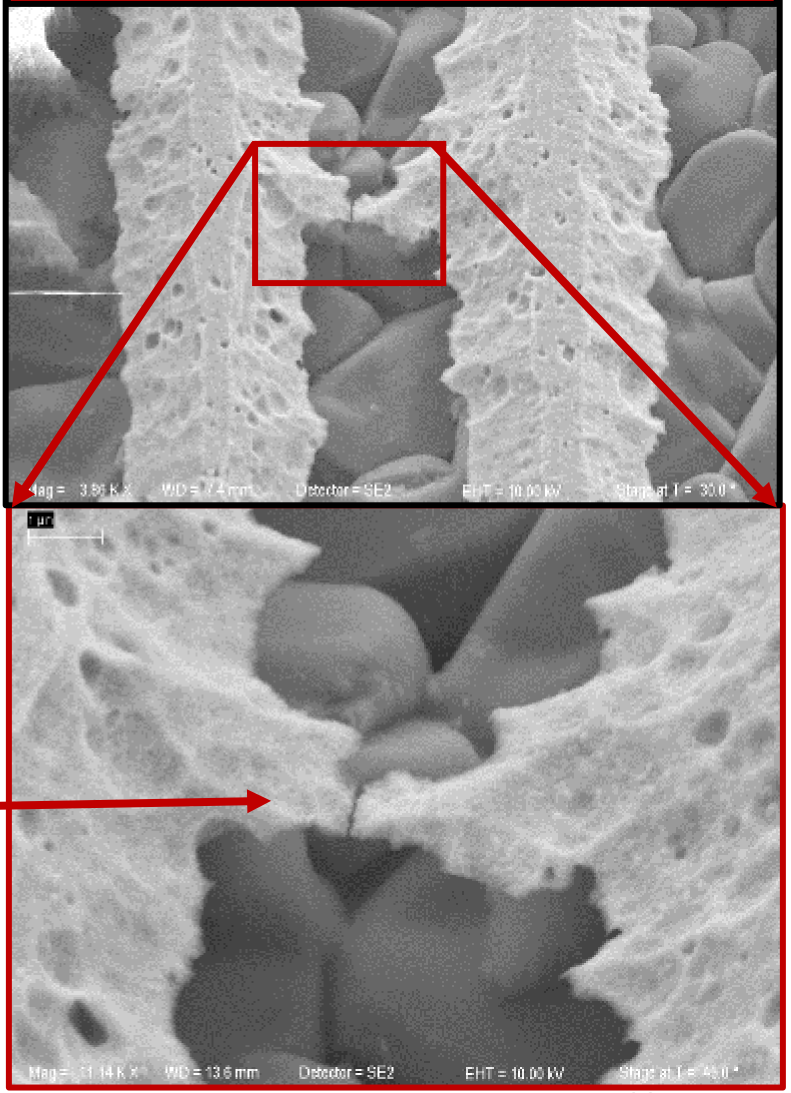
2010, 50kΩ, S/N 48, Type “B”



Pulsed-Power Infrared Screen



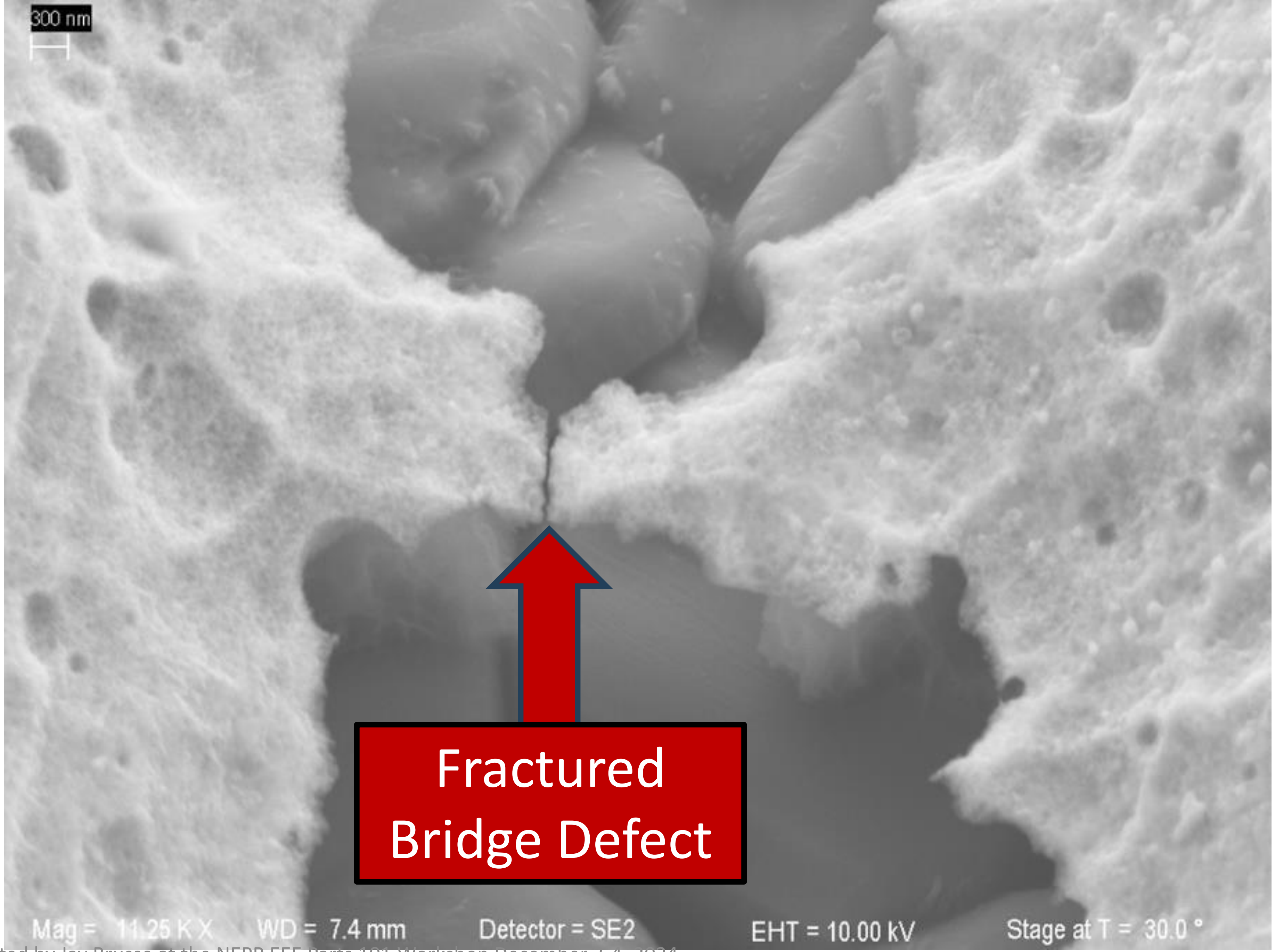
Fractured Bridge



Conclusion:

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

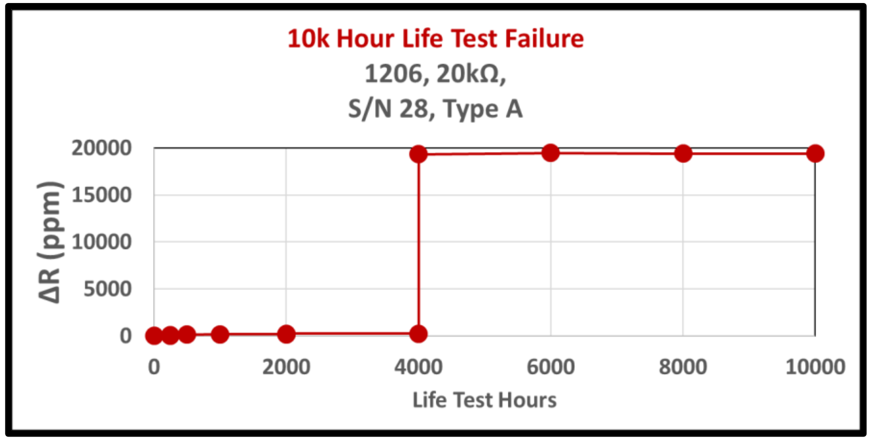
Pulsed-Power Infrared Screen detected this bridge defect as a ‘hot spot’ BEFORE Life Test



Fractured Bridge Defect

Failure Analysis:

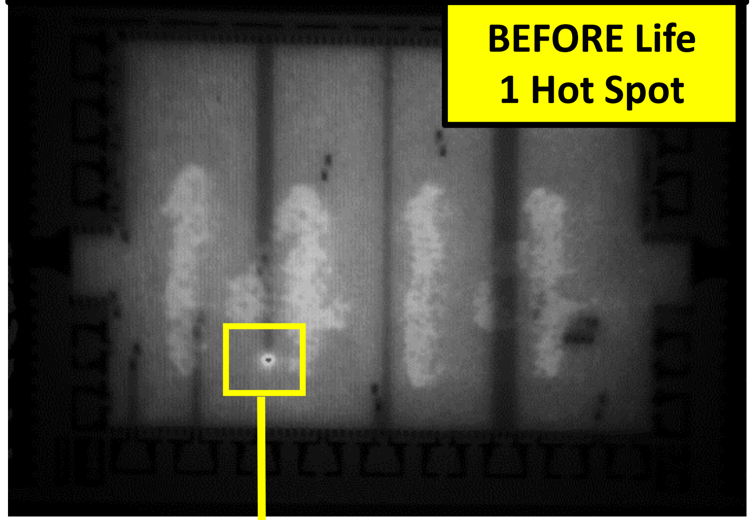
1206, 20kΩ, S/N 28, Type "A"

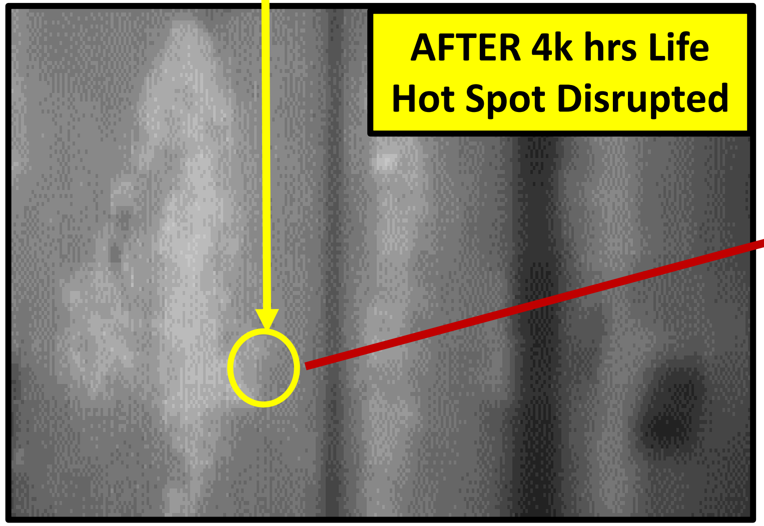

10k Hour Life Test Failure
1206, 20kΩ,
S/N 28, Type A

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

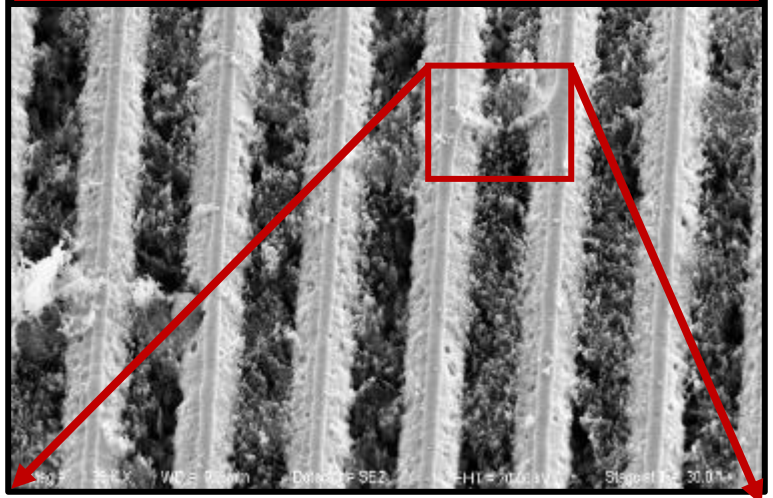
Pulsed-Power Infrared Screen detected this bridge defect as a 'hot spot' BEFORE Life Test

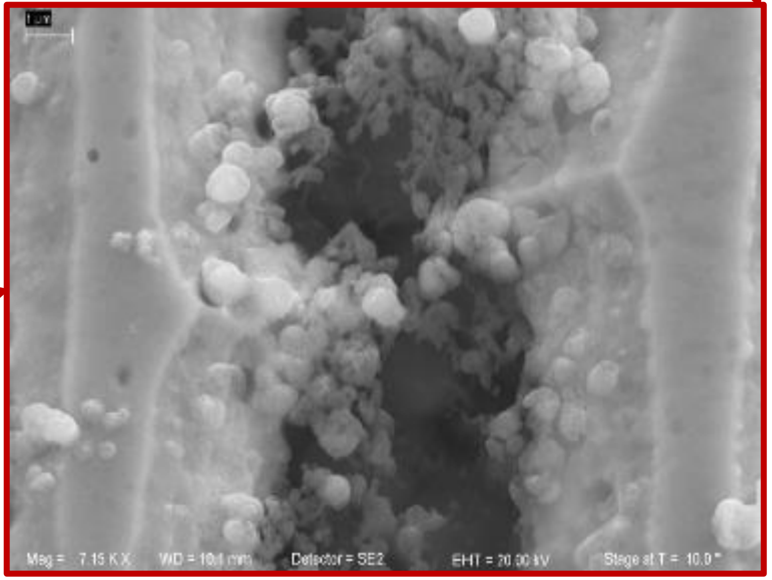
Pulsed-Power Infrared Screen


BEFORE Life
1 Hot Spot


AFTER 4k hrs Life
Hot Spot Disrupted

Fractured Bridge





Conclusions

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

2. **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).

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

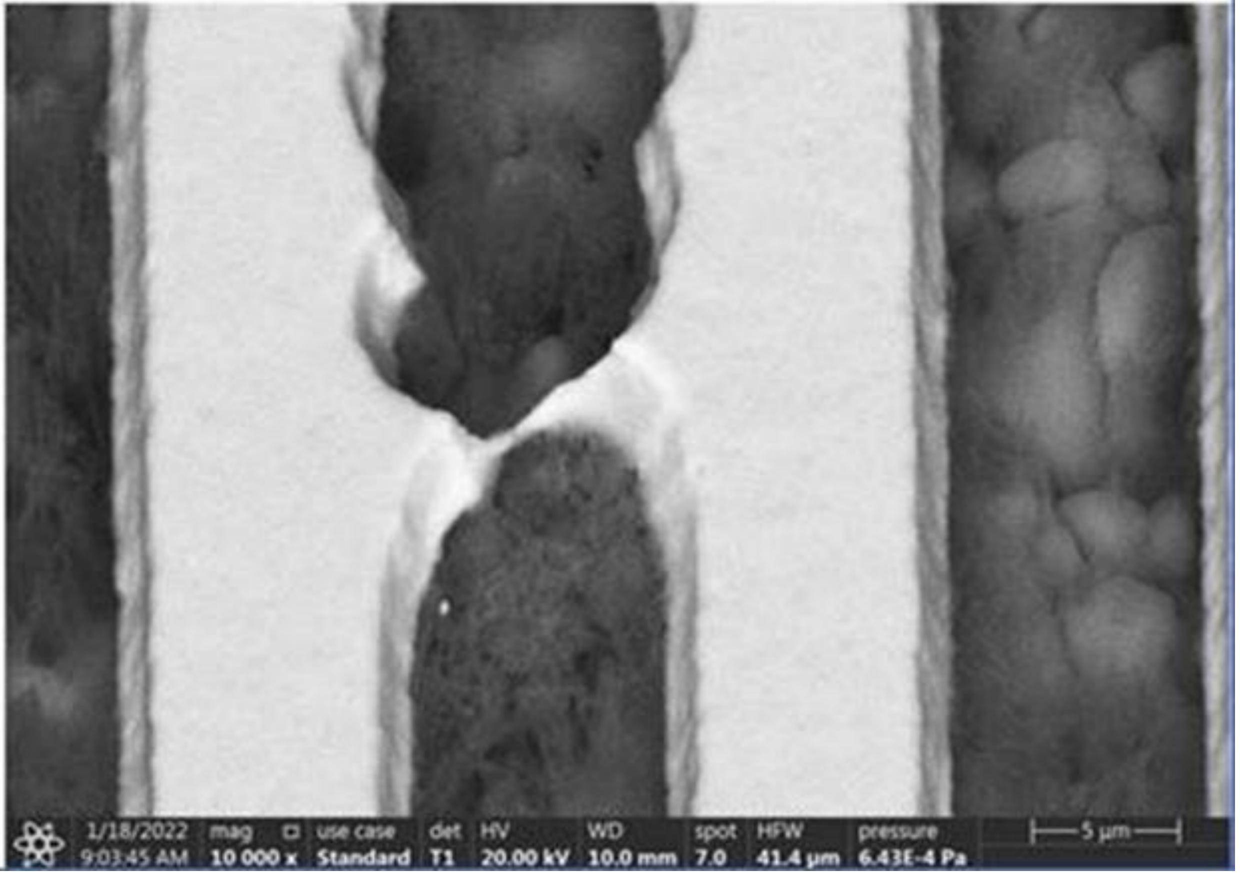
New Screening Technique Can Take a Super Stable Resistor Technology and Make it Super Reliable Too

Questions?

"The Creation of Adam"
- Michelangelo 1511

https://commons.wikimedia.org/wiki/File:Michelangelo_-_Creation_of_Adam_(cropped).jpg

"Bridge Defect"
- Foil Resistor LDC 2040



1/18/2022	mag	use case	det	HV	WD	spot	HFW	pressure
9:03:45 AM	10 000 x	Standard	T1	20.00 kV	10.0 mm	7.0	41.4 µm	6.43E-4 Pa

Acknowledgements

Work Performed in Support of the

NASA Electronic Parts & Packaging (NEPP) Program

Mike Sampson Manager, NASA Electronic Parts & Packaging Program	**Dr. Henning Leidecker** Chief Parts Engineer, NASA Goddard Space Flight Center
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

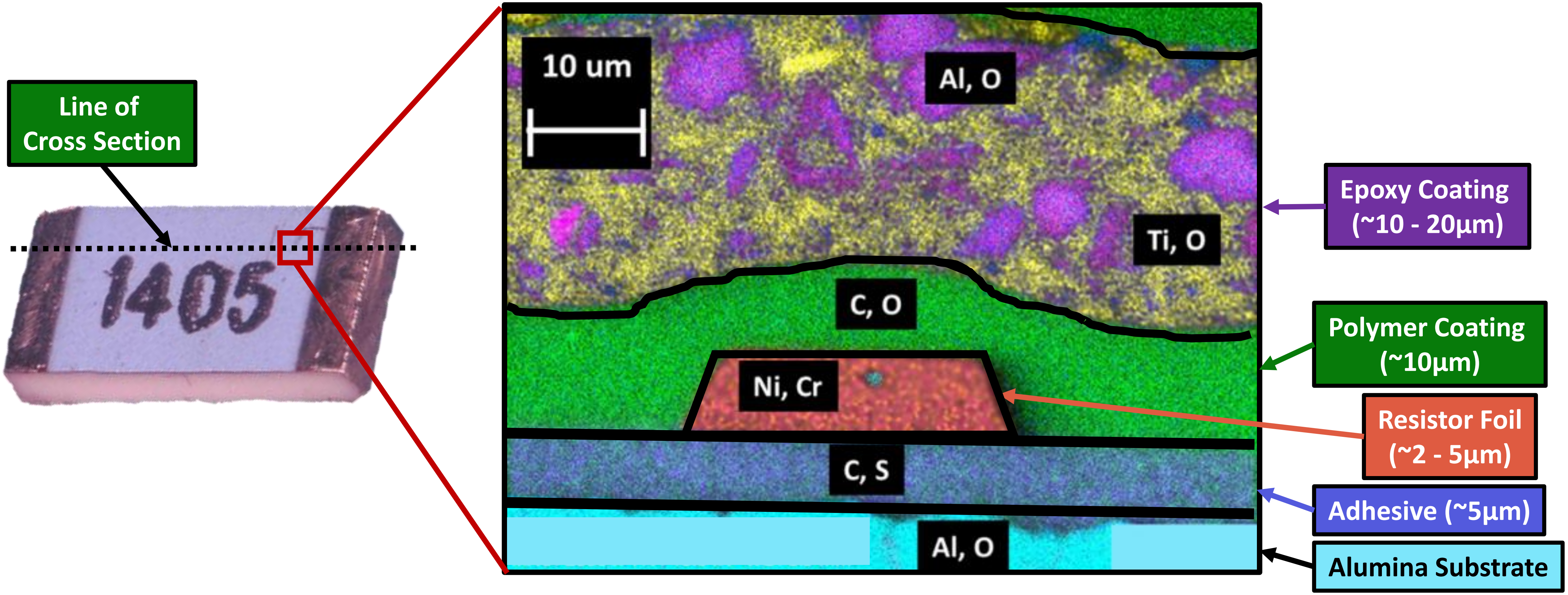
High Resolution Infrared Camera with 4x lens option
FLIR SC8200, SC8300 Series

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)

Basic Construction of a SMT Foil Resistor

Cross Section

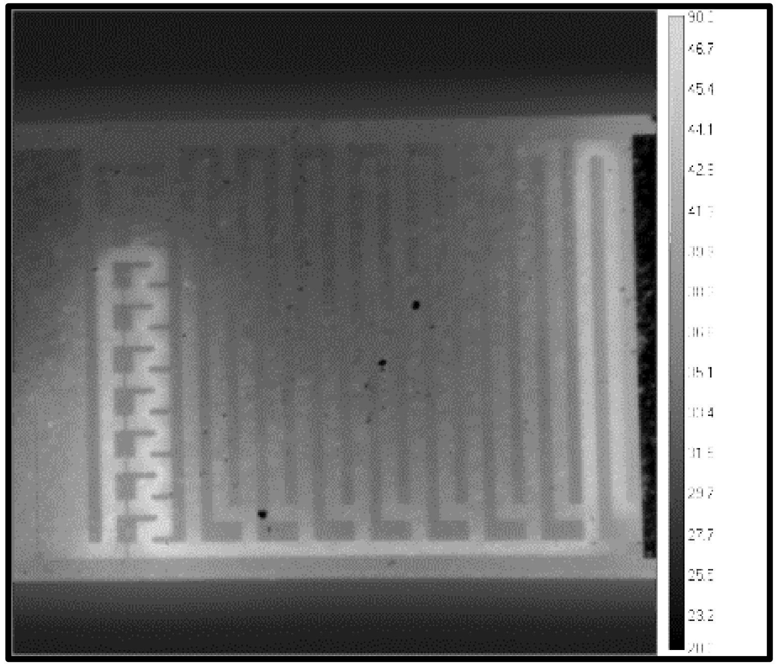
Cross Section

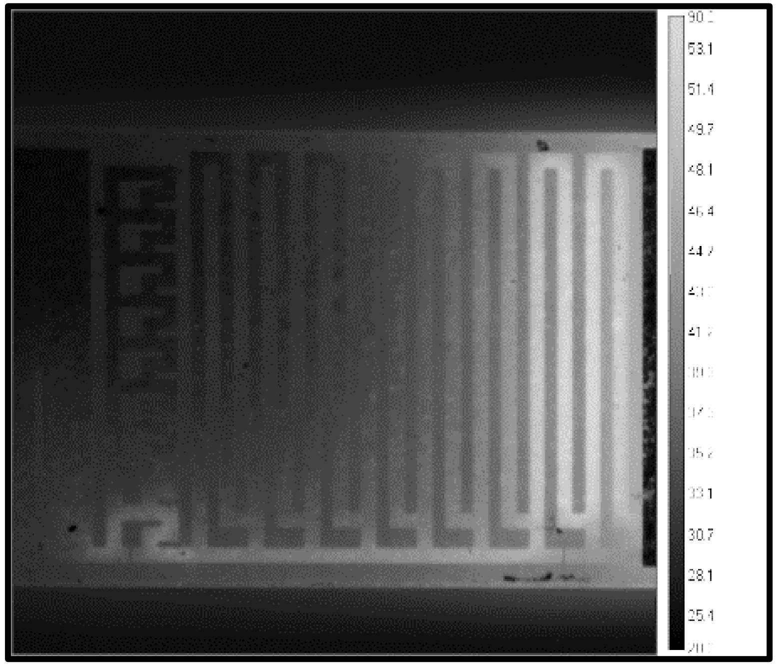


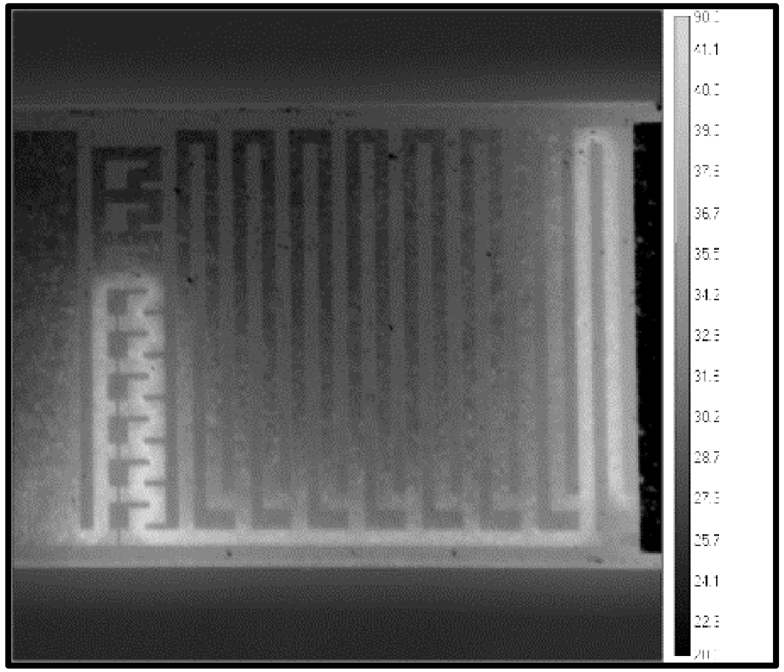
SMT Thin Film Resistors Inspected Using New Pulsed-Power Infrared Screening Method

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

Infrared Inspection Performed Without Removing Resistor Protective Coatings







Foil Resistor with Notch Defect Associated with Embedded Particle