A Screening Method Using Infrared Imaging to Detect Pattern Defects in Foil and Thin Film Resistors

Lyudmyla Panashchenko/NASA Goddard Space Flight Center
Jay Brusse/ASRC AS&D at NASA Goddard Space Flight Center
Matthew King-Smith/The College of Wooster

Acronyms

Al-N = aluminum nitride
InSb = Indium Antimonide
NEPP = NASA Electronic Parts & Packaging (NEPP) Program
NiCr = Nichrome
A Case for an Improved Screening Method: 
System-Level Resistor Failure

• During system-level testing, a NASA program experienced an intermittent open circuit failure of a surface mount Nichrome (NiCr) foil resistor

• Failure analysis identified a fracture in the resistor foil with a non-conductive aluminum nitride (Al-N) particle embedded in the NiCr foil at the failure site

• The particle significantly reduced the cross sectional area of the resistor line leading to ‘hot spot’ generation during powered operation
  • Power cycling lead to thermomechanical fatigue fracture of the localized constriction

• Standard part-level screening practices (e.g., short time overload) failed to detect this flawed resistor
A Case for an Improved Screening Method:

Basic Construction of the Resistor Element

Foil Resistors

• **Resistor Material**
  - NiCr-based alloy is rolled into foil sheets
  - Foil thickness is typically 2 – 5 microns

• **Photolithography**
  - Serpentine patterns are etched into the nichrome foil sheet
  - Etched line widths may be as narrow as a few microns.
  - Resistor pattern consists of series and parallel resistor segments
  - Trim tabs built into pattern allow precise resistance adjustment

• **Bonding Resistor Element to Substrate**
  - NiCr foil is adhesively bonded to an alumina substrate

• **Trimming to Value**
  - Laser (or mechanical scribe) is used to selectively cut trim tabs

• **Protective Coatings**
  - Polymeric coatings encapsulate the resistor element

Basic Construction of the Resistor Element

Foil Resistors

Size 1206
49.9 ohms

Low Values
Have Wider Gridlines
Basic Construction of the Resistor Element

Foil Resistors

Size 1206
49.9 ohms

Low Values
Have Wider Gridlines

Basic Construction of the Resistor Element

Foil Resistors

Size 1206
20,000 ohms

High Values Have Narrower Gridlines

Basic Construction of the Resistor Element

Cross Section of a Surface Mount Foil Resistor

Overview

Cross Section

Opaque Coating (10-20um)
Polymer Coating (~10um)
Resistor Foil (2-5um)
Adhesive (~5um)
Alumina Substrate

Traditional Resistor Screening Methods

Optical Microscopy

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

**Void > 75% in Foil Resistor**

**Bridge < 10% in Foil Resistor**

Traditional Resistor Screening Methods

Short Time Overload

<table>
<thead>
<tr>
<th>Test Conditions</th>
<th>Thin Film (MIL-PRF-55342)</th>
<th>Foil Resistors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Conditions</td>
<td>6.25x rated power for 5 seconds</td>
<td></td>
</tr>
<tr>
<td>Sample Size</td>
<td>20 pcs (space level only)</td>
<td>10 pcs (high reliability products)</td>
</tr>
<tr>
<td>Rejection Criteria</td>
<td>$\Delta R &gt; 0.1%$</td>
<td>$\Delta R &gt; 0.02%$</td>
</tr>
</tbody>
</table>

It is claimed that this test will force failure of devices with the most severe pattern constrictions.

## Traditional Resistor Screening Methods

### Power Conditioning (Also referred to as Burn-In)

<table>
<thead>
<tr>
<th></th>
<th>Thin Film (MIL-PRF-55342)</th>
<th>Foil Resistors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test Conditions</strong></td>
<td>1.5x rated power for 100 hours at 70°C</td>
<td></td>
</tr>
<tr>
<td><strong>Sample Size</strong></td>
<td>100% (space level only)</td>
<td>100% (high reliability products only)</td>
</tr>
<tr>
<td><strong>Rejection Criteria</strong></td>
<td>ΔR &gt; 0.2%</td>
<td>ΔR &gt; 0.03%</td>
</tr>
</tbody>
</table>

*It is claimed that this test will force failure of devices with the most severe pattern constrictions*
Resistor Pattern Defects
Constrictions (Voids)

Resistors with these Defects Found By End User Despite Having Been Subjected to Traditional Screening
Resistor Pattern Defects
Narrow Bridges

Resistors with these Defects Found By End User Despite Having Been Subjected to Traditional Screening
Resistor Pattern Defects
Embedded Particles

Resistors with these Defects Found By End User Despite Having Been Subjected to Traditional Screening
Resistor Pattern Defects
Potential Effects of “Constrictions” in Resistor Lines

- Localized constriction in the resistor pattern will result in higher current density and ‘hot spot’ formation due to Joule heating during powered operation

- Localized constrictions are more prone to fracture especially during power cycling
  - Failure Mechanism = thermomechanical fatigue fracture
  - Failure Modes = open circuit or shift in resistance

- ‘Hot spots’ can also cause thermal decomposition of protective coatings and adhesives (> ~300°C) whose byproducts may accelerate failure
  - Failure Mechanism = stress corrosion cracking of resistor element + thermomechanical fatigue fracture
  - Failure Mode = open circuit or shift in resistance
Resistor Pattern Defects
A Model of Joule Heat Propagation at Local Constriction

Thermal Diffusion

The Length (L) that a thermal pulse spreads from its origin in time (t) is:

\[ L = \sqrt{D \times t} \]

where \( D \) is the thermal diffusivity of the material.

\[ D(\text{copper}) \approx 1.2 \text{ cm}^2/\text{s}; \]
\[ D(\text{nichrome}) \approx 0.11 \text{ cm}^2/\text{s} \]

For example, the distance the pulse spreads in 50 ms is

\[ L = 0.074 \text{ cm} = 0.74 \text{ mm}. \]
New Screening Method for Resistor Pattern Defects

*High Resolution Infrared Thermography During Power Pulsing*

1. Examine resistor using high resolution infrared camera able to resolve features ~10 um or smaller

2. Apply brief power pulses (a few pulses are sufficient)
   - For example, 6.25x rated power, 50 ms, 10% duty cycle
   - Brief pulses dynamically confine the Joule heating to the “local constrictions” in the pattern
   - Brief duty cycle allows resistor to cool to ambient conditions before subsequent pulse

3. Analyze infrared images for localized “hot spots” within the pattern
   - Hot spots are indicative of constrictions (e.g., voids, bridges, embedded particles)

4. A conservative criteria:
   *Reject parts exhibiting significant “hot spots”*

New Screening Method for Resistor Pattern Defects
High Resolution Infrared Camera with 4x lens option

Detector Type | Indium Antimonide (InSb)
Spectral Range | 3.0 - 5.0 µm
Resolution | ~4µm
Frame Rate | Up to 132 Hz (frames per second)
Standard Temperature Range | -20°C to 500°C (-4°F to 932°F)
Accuracy | ±2°C or ±2% of Reading

New Screening Method for Resistor Pattern Defects

Comparison of Two Different Infrared Cameras

The same resistor having 2 constriction defects is examined

FLIR SC660 with 25 micron detector pitch
FLIR SC8300HD with 4 micron detector pitch

1 hot spot detected?

New Screening Method for Resistor Pattern Defects

High Resolution Infrared Camera Identifies Hot Spots During Powered Operation

Infrared Video Demonstration

2kΩ Foil Resistor; Size 1206; Ten 50 ms pulses at 6.25x Rated Power

Notice the “cooler” serpentine lines Associated with “uncut” trim tabs

Bridge

Constriction

New Screening Method for Resistor Pattern Defects

The Protective Coatings are Transmissive at These Infrared Wavelengths

This feature enables use of this technique as a post-procurement screening inspection

Optical Image

Infrared Image
Using FLIR SC8300 Camera with spectral range 1.5 to 5.0 microns

Infrared Image of UNPOWERED Resistor
Example Inspection with New Method

Foil Resistor with Multiple Bridge Defects as Seen in Infrared

Applying 6.25x Rated Power for 50 ms pulses; 10% duty cycle

Example Inspection with New Method
Foil Resistor with Two Bridge Defects as Seen in Infrared
Applying 6.25x Rated Power for 50 ms pulses; 10% duty cycle

Inspection Performed Without Removing Resistor Protective Coatings
Example Inspection with New Method
Foil Resistor with Two Local Constriction Defects as Seen in Infrared
Applying 6.25x Rated Power for 50 ms pulses; 10% duty cycle

Inspection Performed Without Removing Resistor Protective Coatings
Example Inspection with New Method
Foil Resistor with One Local Constriction Defect as Seen in Infrared
Applying 6.25x Rated Power for 50 ms pulses; 10% duty cycle

Inspection Performed Without Removing Resistor Protective Coatings
Example Inspection with New Method
Foil Resistor with One Local Constriction Defect as Seen in Infrared
Applying 6.25x Rated Power for 50 ms pulses; 10% duty cycle

Inspection Performed Without Removing Resistor Protective Coatings
Conclusions

• NASA has developed a method to detect pattern defects in foil and thin film resistors using high resolution infrared thermography while applying brief power pulses

• The technique can be used at various stages:
  • In-process screen by resistor manufacturer prior to protective coating application
  • Post-procurement screen by end user if coatings are transmissive at infrared wavelengths
  • Destructive physical analysis and failure analysis

Future Work

• NASA plans to evaluate reliability of suspect parts identified by this method
  • Long-term life test comparison of suspect vs. non-suspect parts

## Acknowledgements

Work Performed in Support of the NASA Electronic Parts & Packaging (NEPP) Program

<table>
<thead>
<tr>
<th>Mike Sampson</th>
<th>Dr. Henning Leidecker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manager, NASA EEE Parts &amp; Packaging (NEPP) Program</td>
<td>Chief Parts Engineer, NASA Goddard Space Flight Center</td>
</tr>
<tr>
<td><a href="mailto:Michael.J.Sampson@nasa.gov">Michael.J.Sampson@nasa.gov</a></td>
<td><a href="mailto:Henning.W.Leidecker@nasa.gov">Henning.W.Leidecker@nasa.gov</a></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tim Mondy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Engineer, Arctic Slope Regional Corporation @ NASA-GSFC</td>
</tr>
<tr>
<td><a href="mailto:Timothy.K.Mondy@nasa.gov">Timothy.K.Mondy@nasa.gov</a></td>
</tr>
</tbody>
</table>
Backup Slides
Basic Construction of the Resistor Element

Thin Film Resistors

- **Resistor Material**
  - Typically a NiCr or Tantalum Nitride-based alloy sputter deposited onto an alumina substrate
  - Film thickness typically 50 nm to 250 nm

- **Photolithography**
  - Serpentine patterns are etched into the thin film
  - Etched line widths as narrow as a few microns
  - Pattern consists of both series and parallel resistor segments
  - Coarse, Intermediate and fine adjustment pattern features are built into the pattern

- **Trimming to Value**
  - Laser is used to selectively remove thin film resistor material

- **Protective Coatings**
  - Polymeric coatings encapsulate the resistor element

Example Inspection with New Method

Thin Film Resistors as Seen in Infrared
Applying 6.25x Rated Power for 100 ms pulses; 10% duty cycle

Inspection Performed
Without Removing
Resistor Protective
Coatings

Example Inspection with New Method
Thin Film Resistors as Seen in Infrared
Applying 6.25x Rated Power for 100 ms pulses; 10% duty cycle

Inspection Performed Without Removing Resistor Protective Coatings