APPLICATIONS FOR EMBEDDED NiP Thin Film Resistors in Printed Circuit Boards

Bruce P Mahler
Vice President
Ohmega Technologies, Inc.

November 13, 2019

PCB Carolina 2019

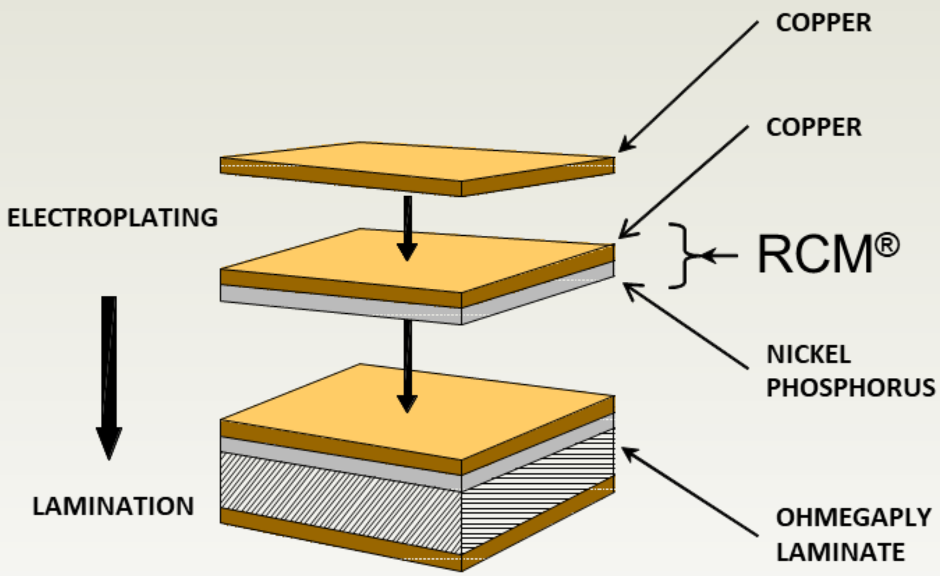
Ohmega Technologies Inc.

Why Embedded Resistors?

- **Density**
  - Free up board surface area.
  - Reduce board size or add functionality.
- **Electrical Performance Enhancement**
  - Shorter electrical connections.
  - Lower inductance.
  - Reduced EMI.
- **Potential Cost Reduction**
  - Lower component and assembly costs.
  - Smaller board area.
  - Improved assembly yield.
- **Improved Reliability and Manufacturability**
  - Fewer solder joints.
  - Potential for single-sided assembly.

NiP Thin-Film Manufacturing Overview

The Nickel Phosphorus (NiP) metal alloy is electrodeposited onto copper foil. The thin film NiP metal alloy/copper foil combination is called OhmegaPly RCM® (Resistor-Conductor Material). The RCM is laminated to a dielectric material, like any other copper foil, and subtractively processed to produce copper circuitry and planar resistors.

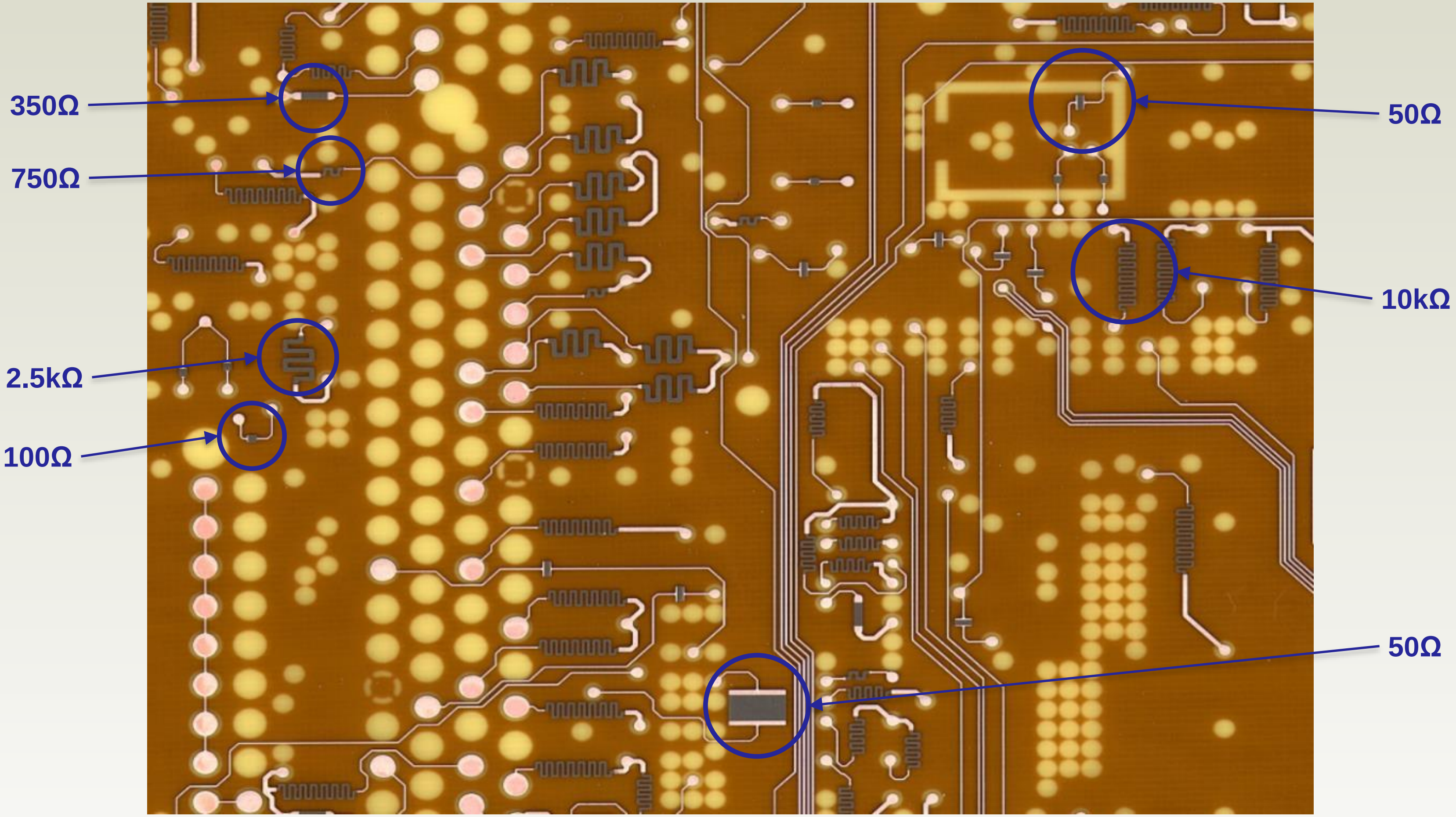


NiP Thin-Film Sheet Resistivity Options

Sheet Resistivity (Ω/□)	Material Tolerance (%)	Typical Applications
10 Ω/□	3	Developed for series termination resistors as ORBIT® (Ohmega Resistors Built-In Trace) and other applications like heaters.
25 Ω/□	5	Used primarily for series /parallel termination resistors, filters and RF/Microwave power dividers.
40 Ω/□	5	
50 Ω/□	5	
100 Ω/□	5	Used primarily as pullup/pulldown resistors for digital logic circuits.
250 Ω/□	10	High ohmic applications.
377 Ω/□	10	RF/Microwave R-card, absorbers

Ohms Per Square
Many possible values per sheet resistivity

Example: Pull-up/down and termination resistors military/aerospace board



PCB Carolina 2019

Split Trace Thin Film Fractional Resistor

A patent pending design approach for creating ultra low ohm (<1Ω) resistor values. Solution for current sensing applications.

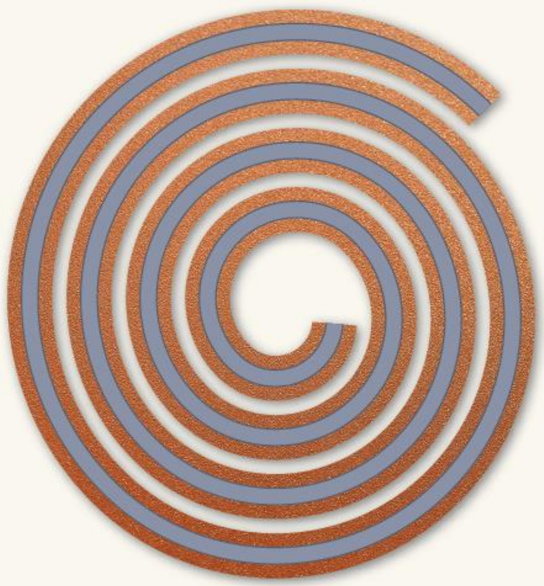


Image 1
Split Trace Spiral 0.004 Rs
Example: 0.004 Rs * 10 ohms/square = 0.04 ohms

Image 2
Split Trace 0.02Rs
Example: 0.02Rs * 10 ohms/square = 0.2 ohms

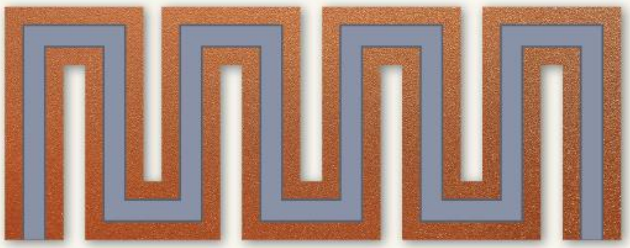
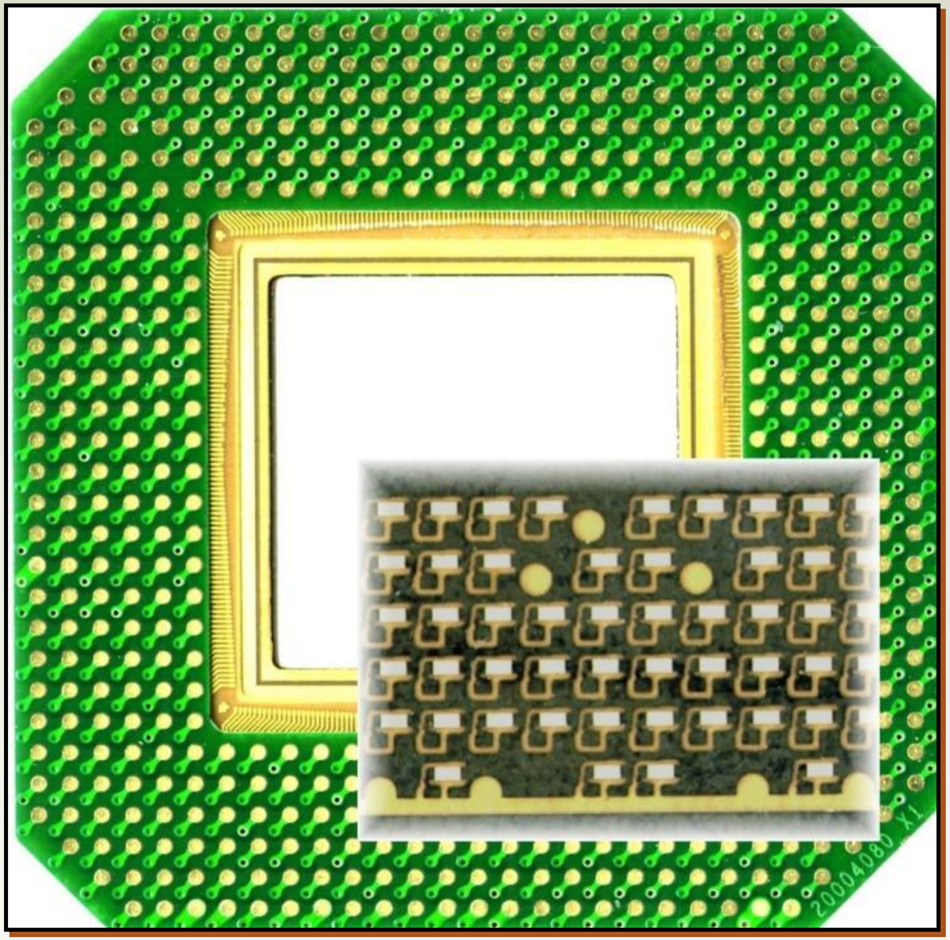


Image 3
Split Trace Meander 0.01Rs
Example: 0.01Rs * 10 ohms/square = 0.1 ohms

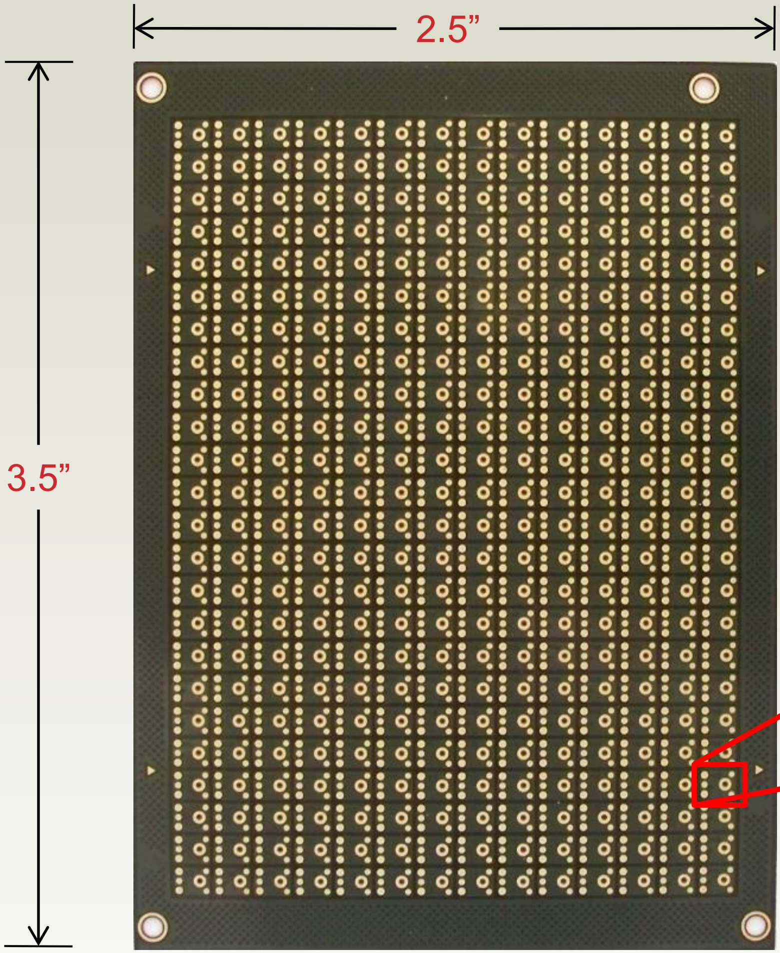
NiP Applications:
Interposer Computer & Telecom Electronics



PCB Carolina 2019

Parallel termination resistors

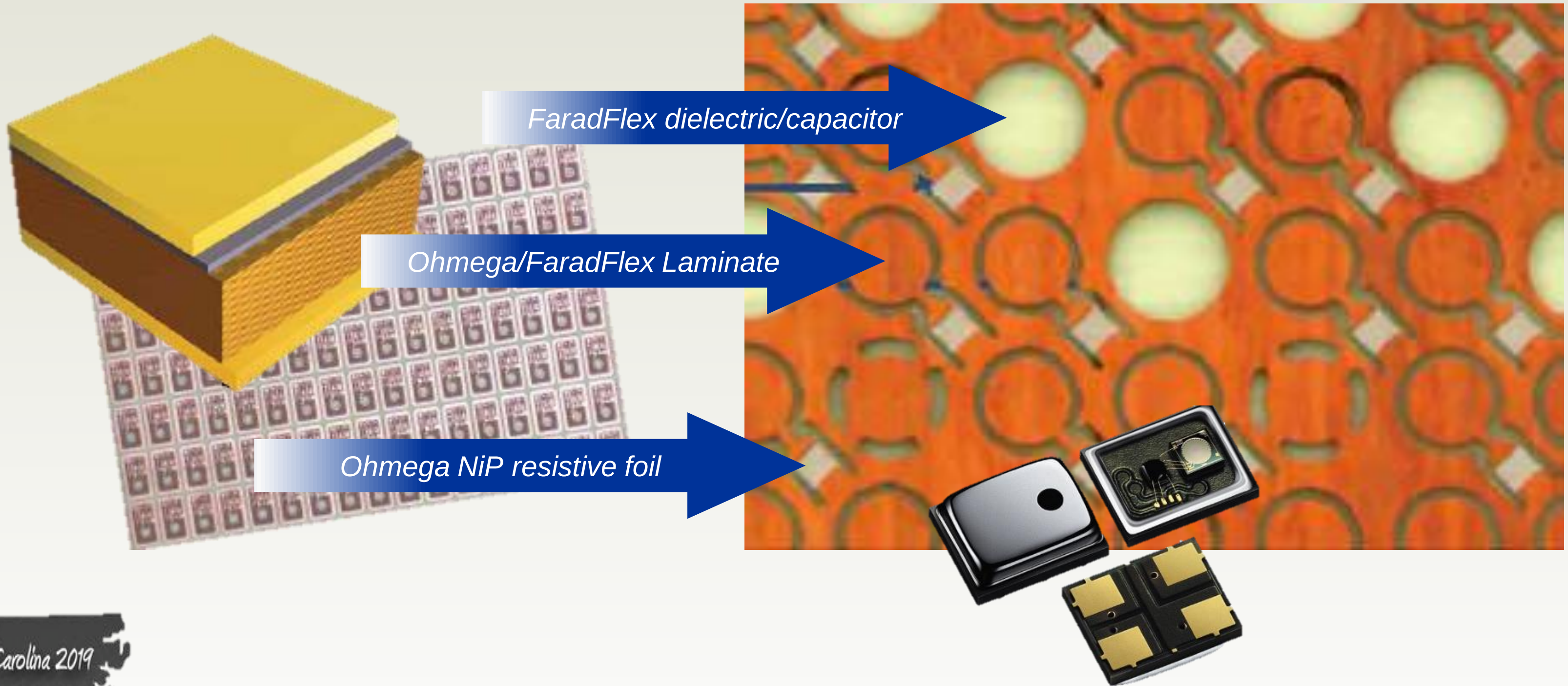
NiP Applications:
MEMS Microphones Consumer Electronics



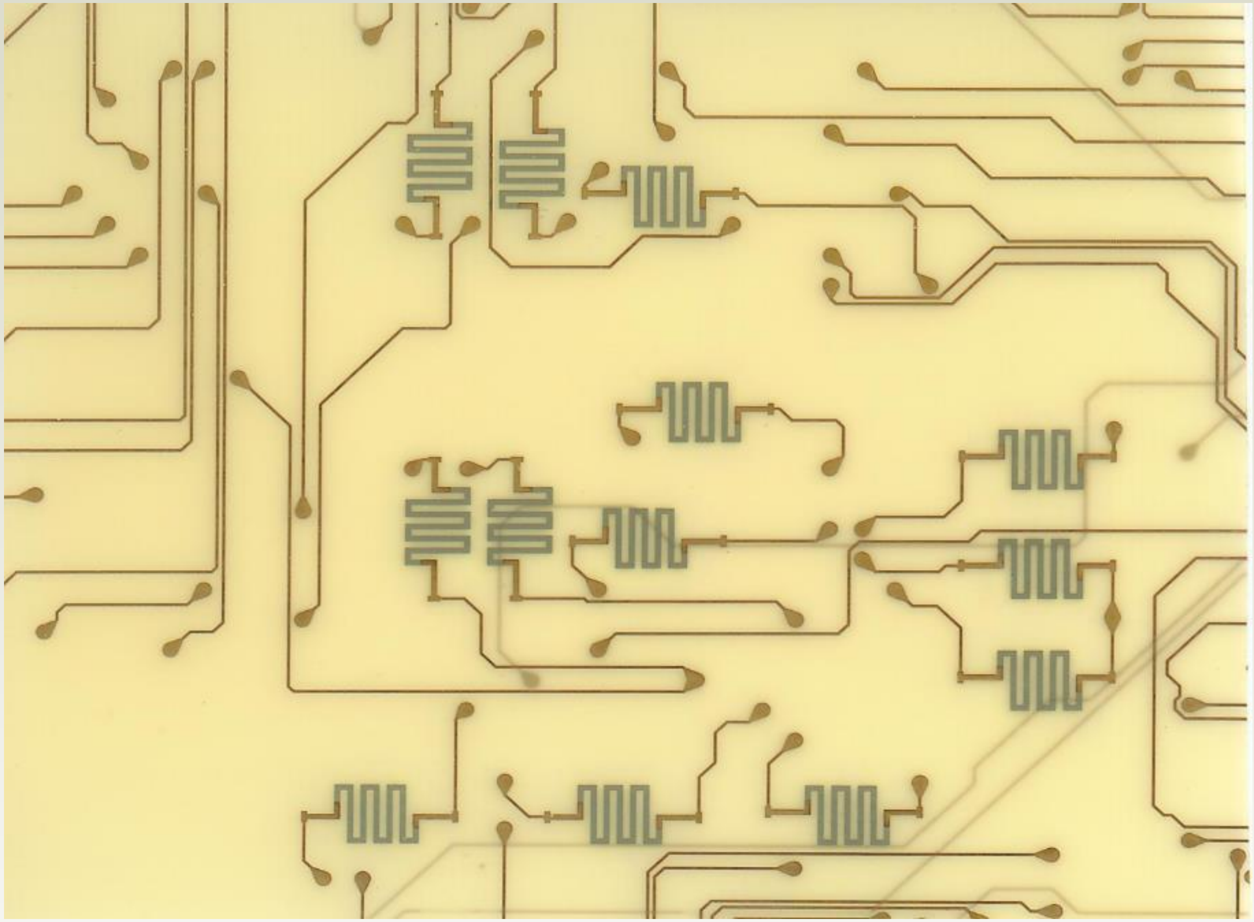
NiP Applications:
MEMS Microphones Consumer Electronics

Embedded Resistance-Capacitance Technology

Ohmega®/*FaradFlex*® is a combined product of the *Ohmega*® thin film resistive-conductive material (RCM) laminated to a *FaradFlex*® dielectric material and subtractively processed to produce embedded RC Networks. It is a jointly owned patented product of Ohmega Technologies, Inc. and Mitsui Mining

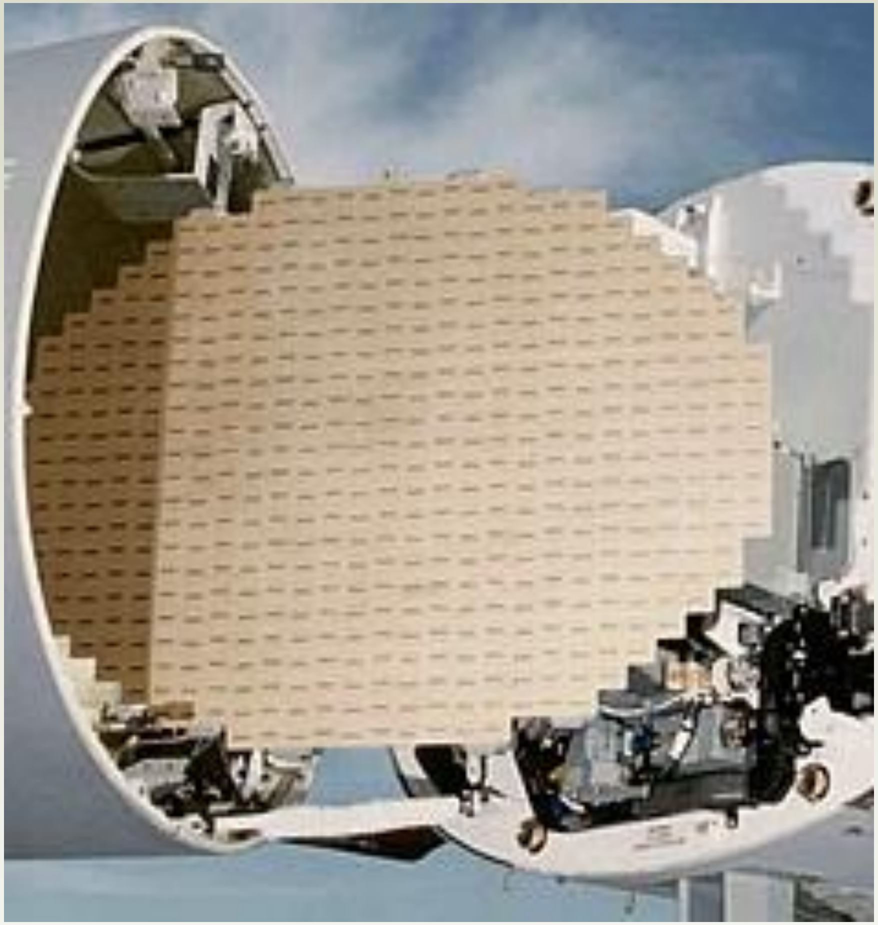


NiP Applications: Military/Aerospace



Pull-up/down resistors

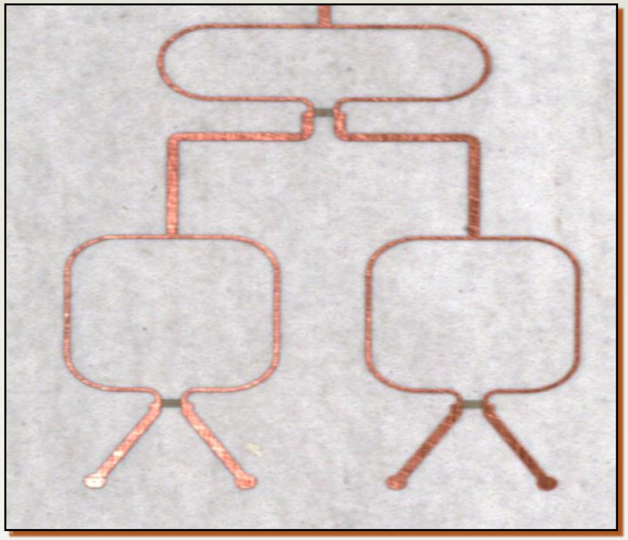
NiP Applications: Military/Aerospace



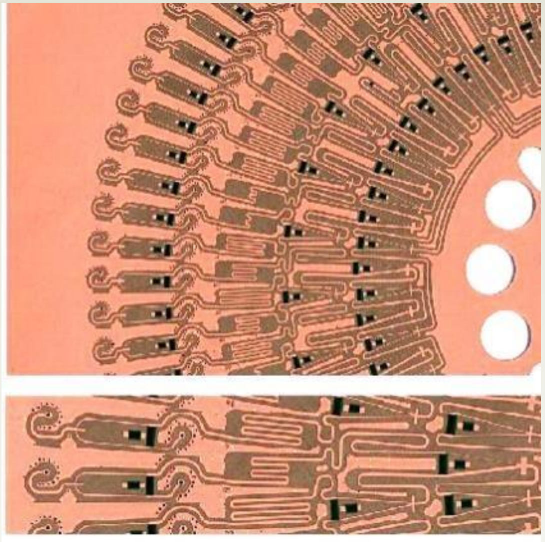
Power Divider in Active Phased Array Antenna

NiP Applications: Military/Aerospace and Commercial Microwave

NiP thin-film resistors have found extensive use in RF and microwave circuits including those operating beyond 50 GHz. The benefits include eliminating solder joints, greater packaging densities and reducing parasitic inductance and capacitance.



Enlargement of a four-up array 16-way power divider with 50 Ω/sq NiP resistors



Passive feed network for Globalstar antenna array 50 Ω/sq NiP resistors

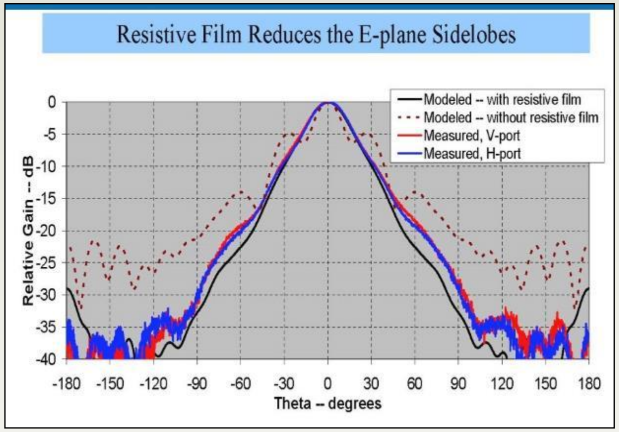
PCB Carolina 2019

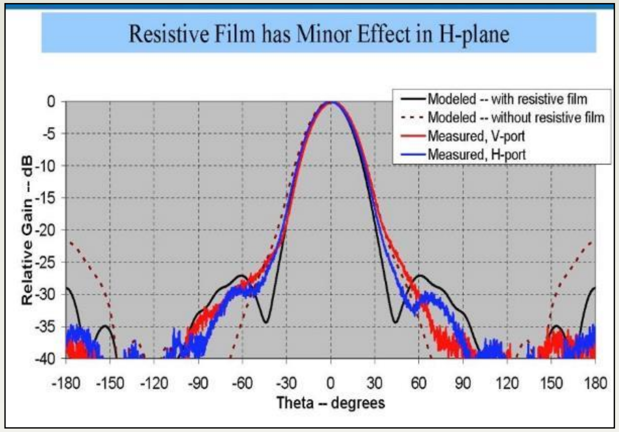
NiP Applications: R-Cards/Absorbers

- Can be laminated to a variety of substrate materials with different permittivities.
- High impedance surfaces (HIS), frequency selective surfaces (FSS).
- Create repetitive, planar 2-D patterns using standard photolithography techniques (subtractive print/etch).
- 3-D structures obtainable through sequential lamination.
- Size, weight and cost reduction.
- Increased bandwidth and improved performance covering wider angles of incidence.

NiP Applications: R-Cards/Absorbers

Target applications include but are not limited to mm-Wave Antennas, Antenna Arrays, Radar Absorbing Materials (RAM), Resistive Cards(R-cards), High Impedance Surfaces (HIS) and Frequency Selective Surfaces (FSS).





* **Data Courtesy of Toyon Research Corporation**

PCB Carolina 2019

NiP Thin-Film Resistors as Heaters in PCBs

Applications include:

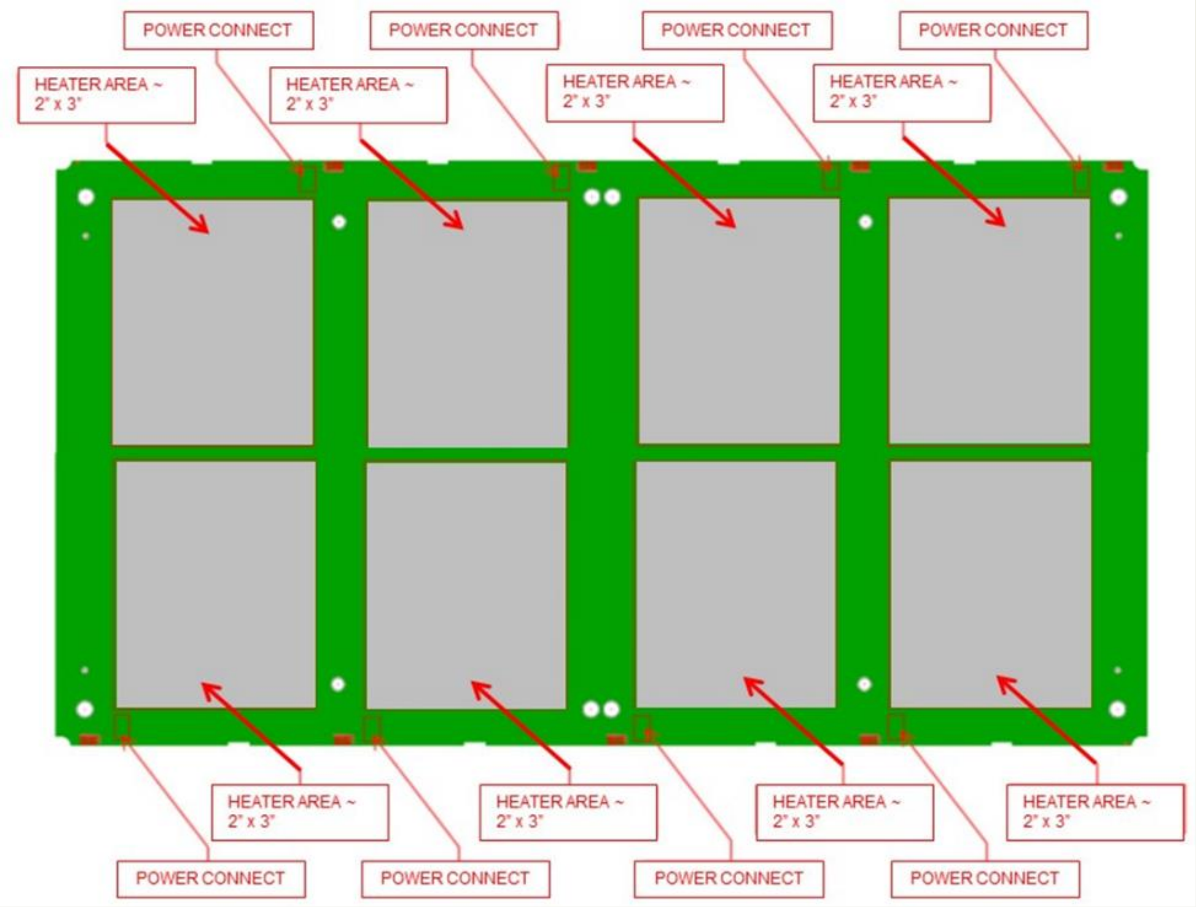
- Aerospace & Defense
  - SAL (semi-active laser) activation guided munitions
  - XRF Spectrometer & Control board (Mars Beagle 2 lander)
  - Satellite solar array deployment mechanism
- Biomedical Electronics
  - Bioassay
  - Drug vaporization for subcutaneous injections
  - Heat therapy for dry eye
- PCB Temperature Control
- IC Testing/Burn-In

NiP Thin-Film Resistors As heaters in PCBs

Advantages of using NiP thin-film resistors are:

- Improved reliability (removal of solder joints)
- Fewer parts to assemble
- Custom resistor footprints
- Fast temperature rise times
- Low RTC characteristic <50 ppm/C (-65C to +125C)
- Stable values at high ambient temperatures (150C+)

NiP Heater Applications: IC Burn-In



PCB Carolina 2019

10 ohm/sq embedded heater array for IC Burn-In testing at 65C

Macro Tuning Technique for Embedded Resistor Elements

A new patent pending design methodology to adjust a resistor nominal value by use of distributed copper islands or voids within the resistor elements.

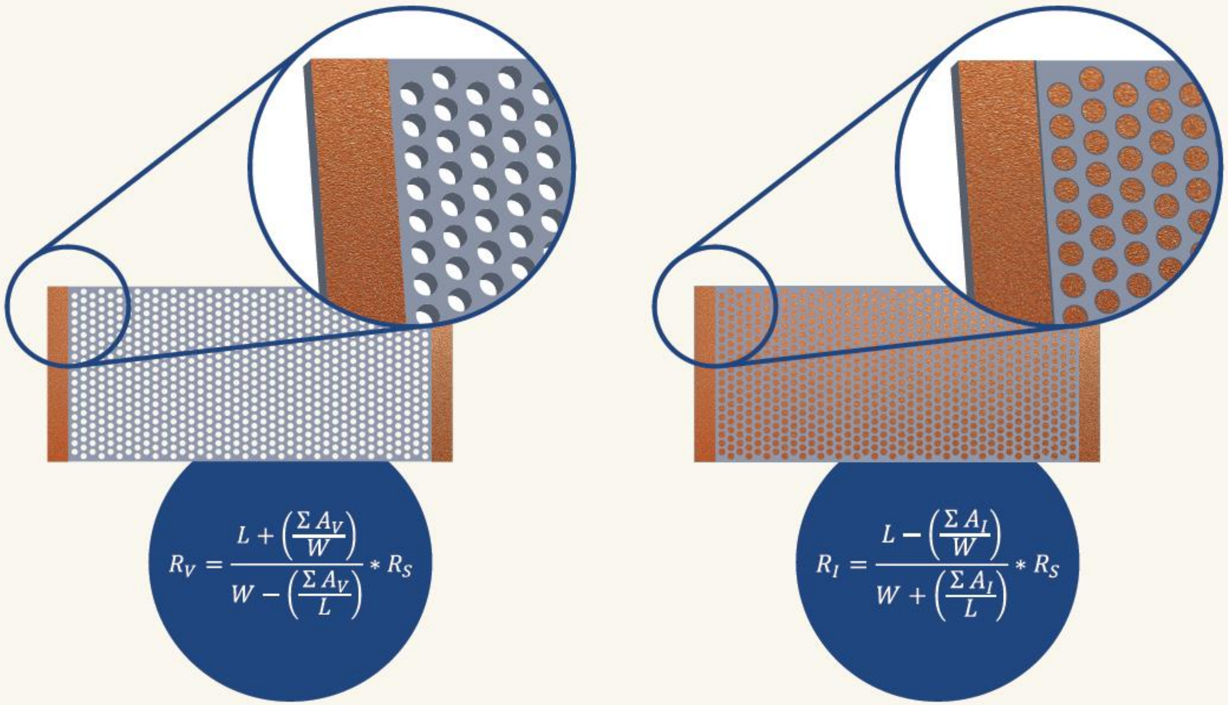


Image 1 Planar resistor with voids in body

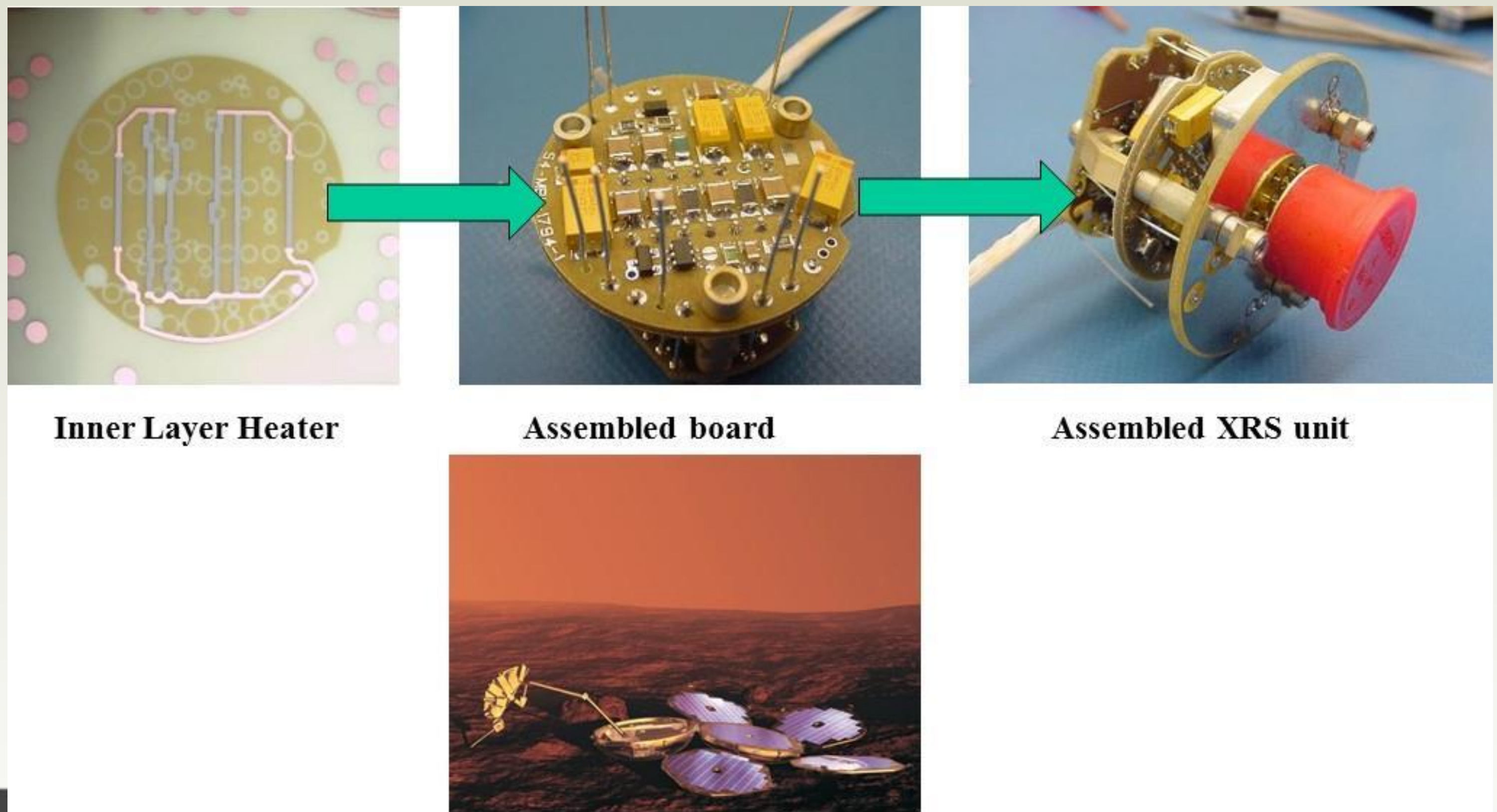
Image 2 Planar resistor with copper islands in body

PCB Carolina 2019

Embedded, large format resistive heaters

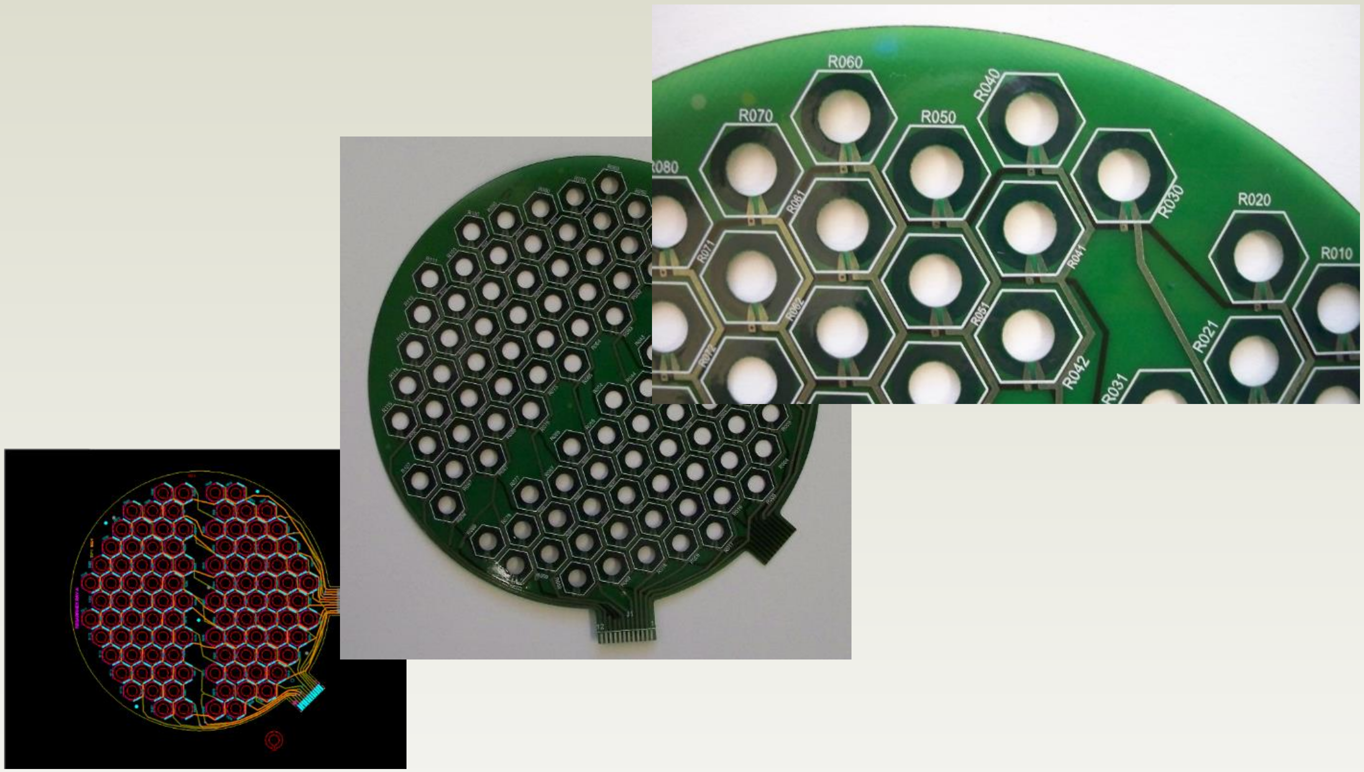
NiP Heater Applications: Space-Based

Application shows a heater used to bring the X-Ray Spectrometer (XRS) biasing and pre-amplification electronics to -50 degrees Celsius in the Mars Beagle 2 Lander.



* **Images Courtesy of the University of Leicester Space Research Centre and the Beagle2 Consortium**

NiP Heater Applications: Biomedical



Example NiP heater array in a biomedical device

NiP MicroHeater Applications: Biomedical, Industrial

- Small area heaters
- Localized heating to precise temperatures
- Growing use in MEMs-based gas sensors in Industrial, Consumer, Automotive and Home Environments, including detecting
  - Carbon monoxide
  - Methane
  - Oxygen

NiP MicroHeater Applications: Lab-On-PCB (LOP)

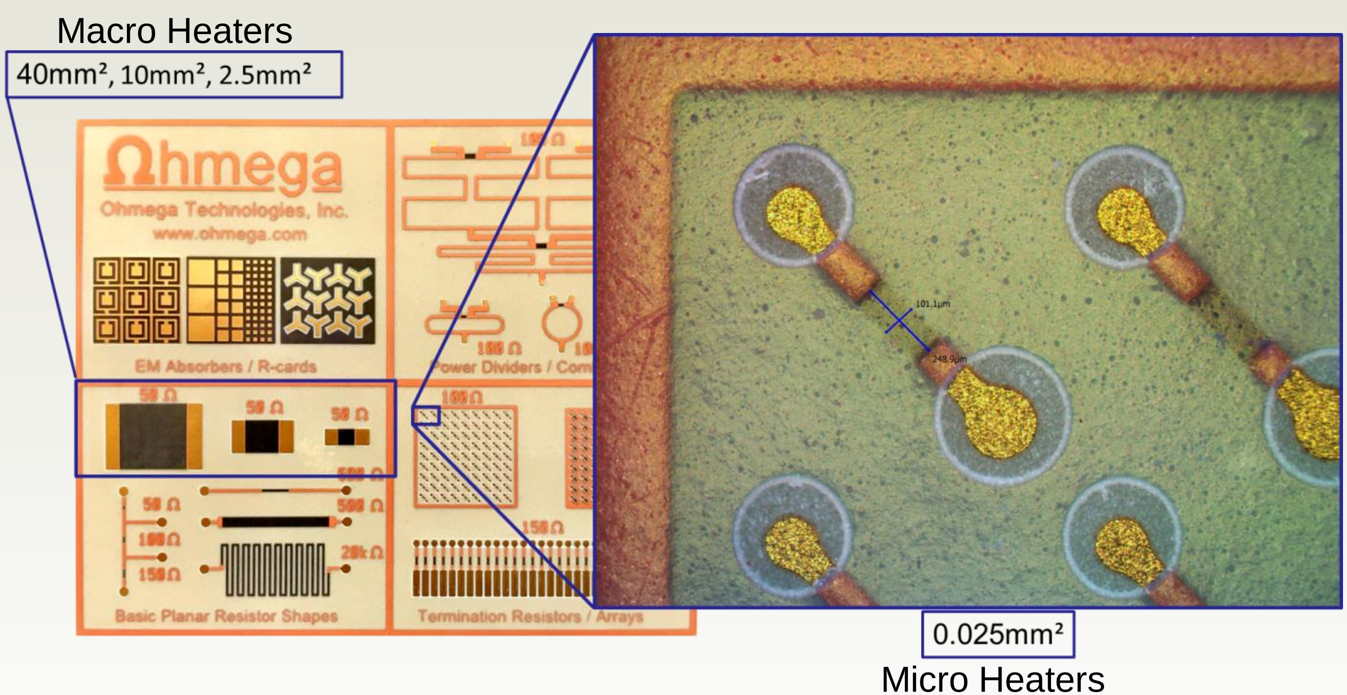
Growing applications for PCB based MEMs and LOP devices. These devices include sensors and microfluidic devices requiring microheaters on, or within, the PCB board.

Advantages of using NiP thin-film resistors in these PCBs are:

- Elimination of discrete chip resistors
- Fewer components to assemble and fewer solder joints
- Custom resistor footprints through subtractive print/etch
- Fast temperature rise and low power
- Resistors embedded within PCB for localized heating
- Reliable, long term use of NiP thin-film resistors as heaters in PCBs

PCB NiP Thin-Film Micro-Heater Definition

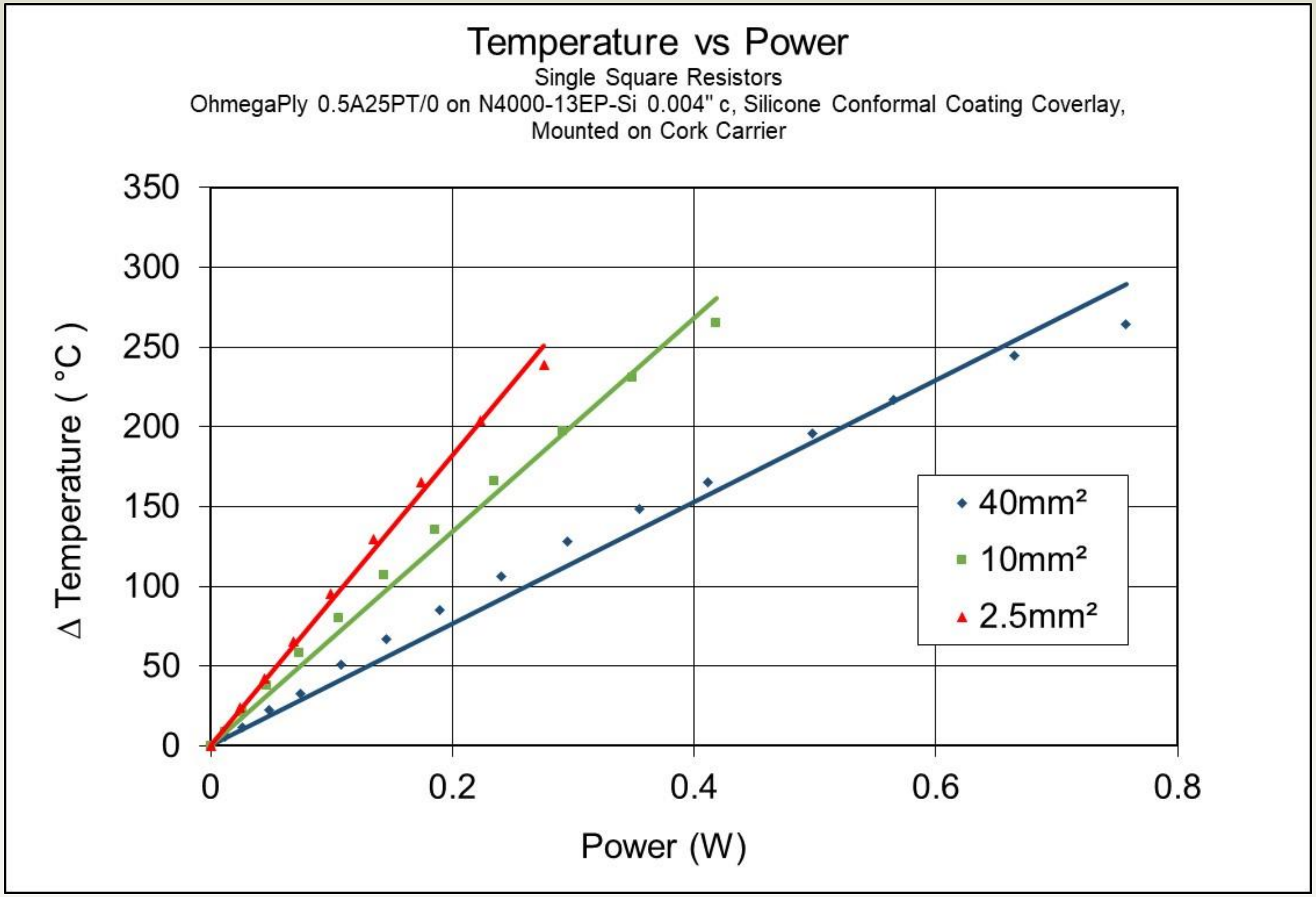
- Micro-Heaters are defined as resistive elements with an area less than 0.25mm².
- For this study, the heater elements were constrained to a rectangular shape with an area of 0.025mm² (0.10mm x 0.25mm).



NiP Thin-Film Micro Heater Testing

- Evaluate NiP Thin-Film Micro Heaters
- Temperature rise vs. power input
- Temperature rise vs. time
- Temperature rise vs. resistor area

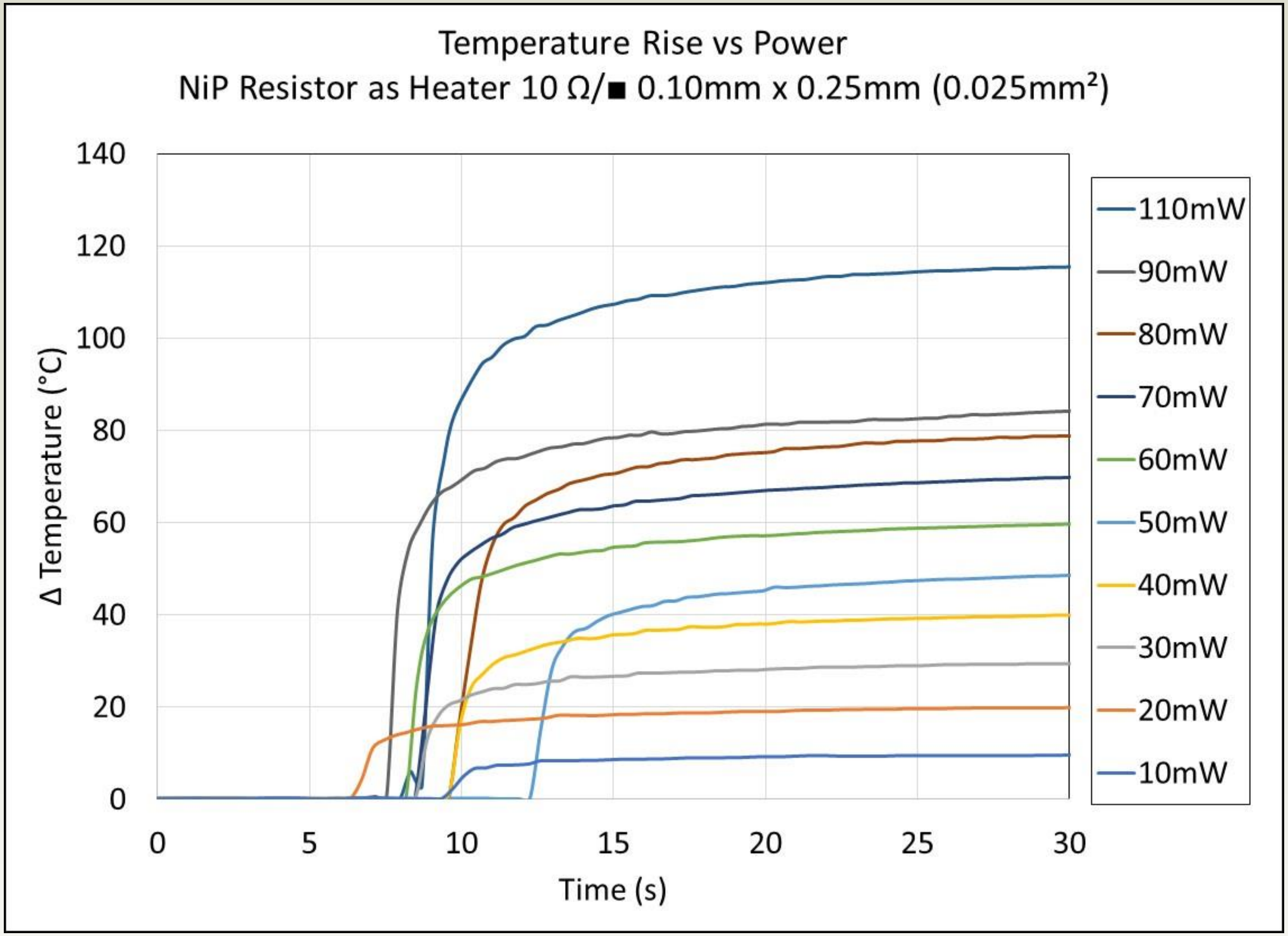
Temperature Rise vs Power for Larger NiP Thin-Film Resistors (Macroheaters)



Temperature Rise versus Power

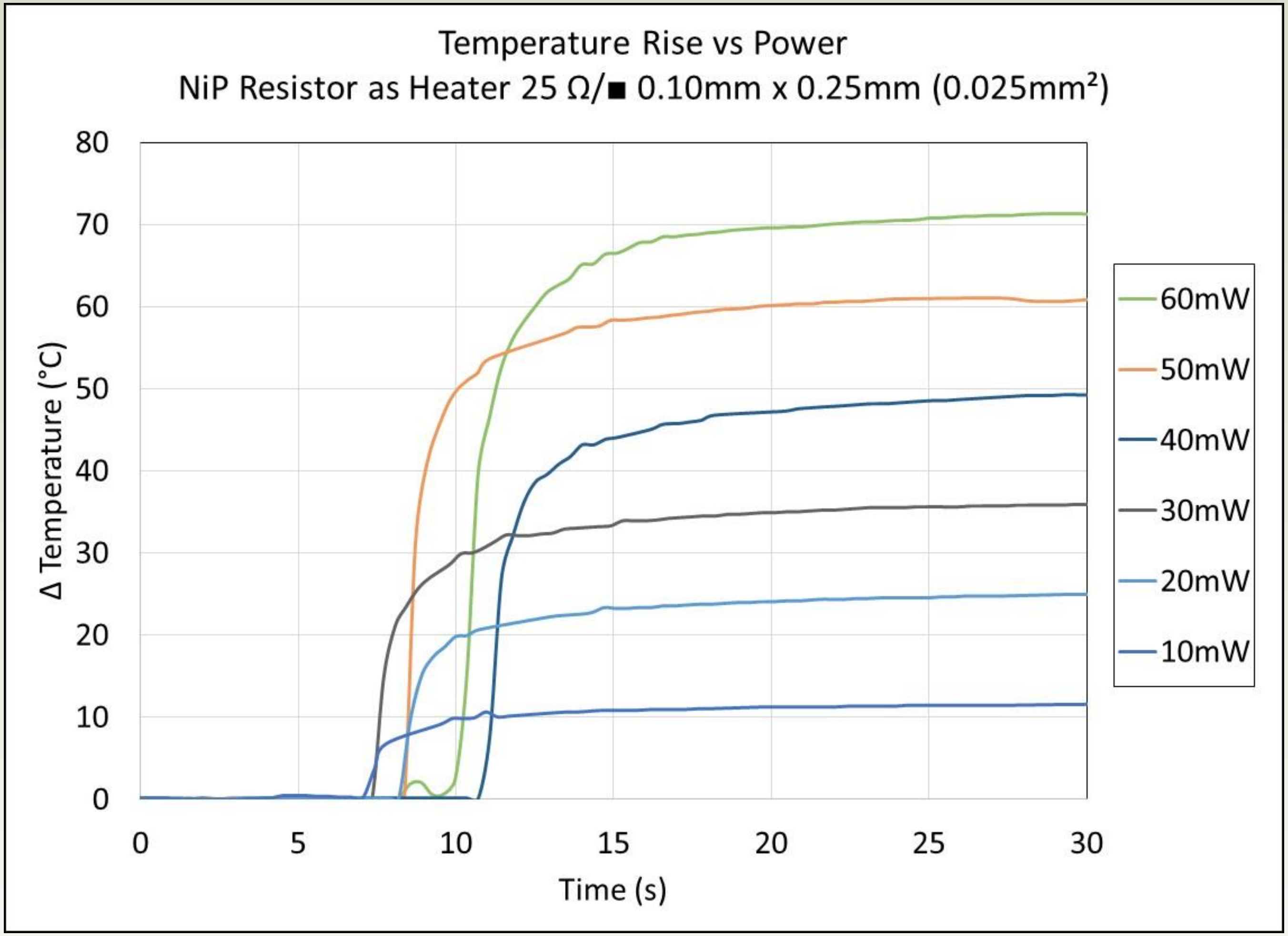
- The tests were conducted comparing temperature versus power input for various NiP sheet resistivities.
- NiP resistor as heaters were tested at a fixed size of 0.025mm^2 (0.10mm x 0.25mm).
- The construction of the test boards were:
  - Isola 370HR, 0.004” core
  - No backside cladding
  - Clear solder mask

Temperature vs Power Data

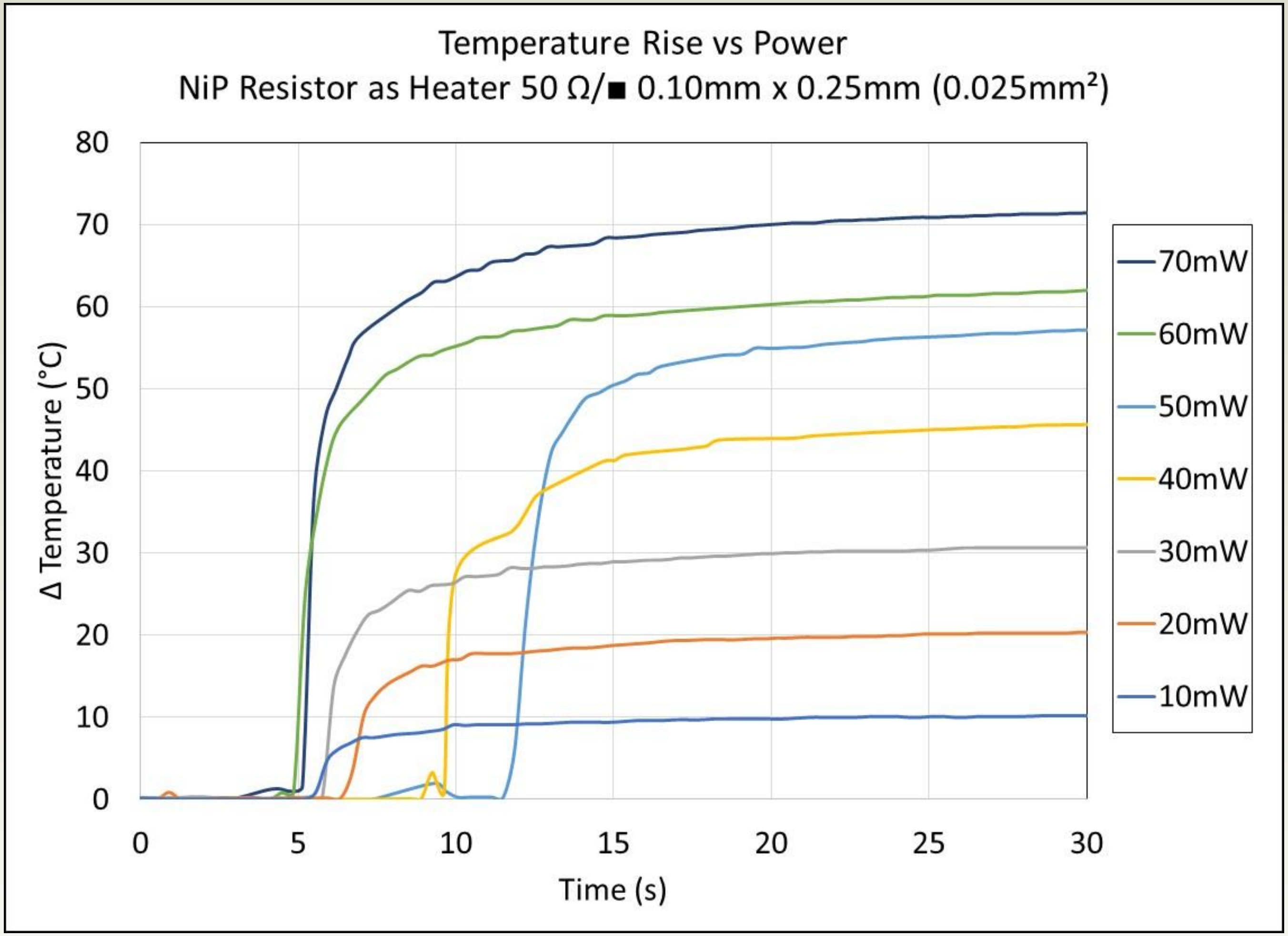


PCB Carolina 2019

Temperature vs Power Data

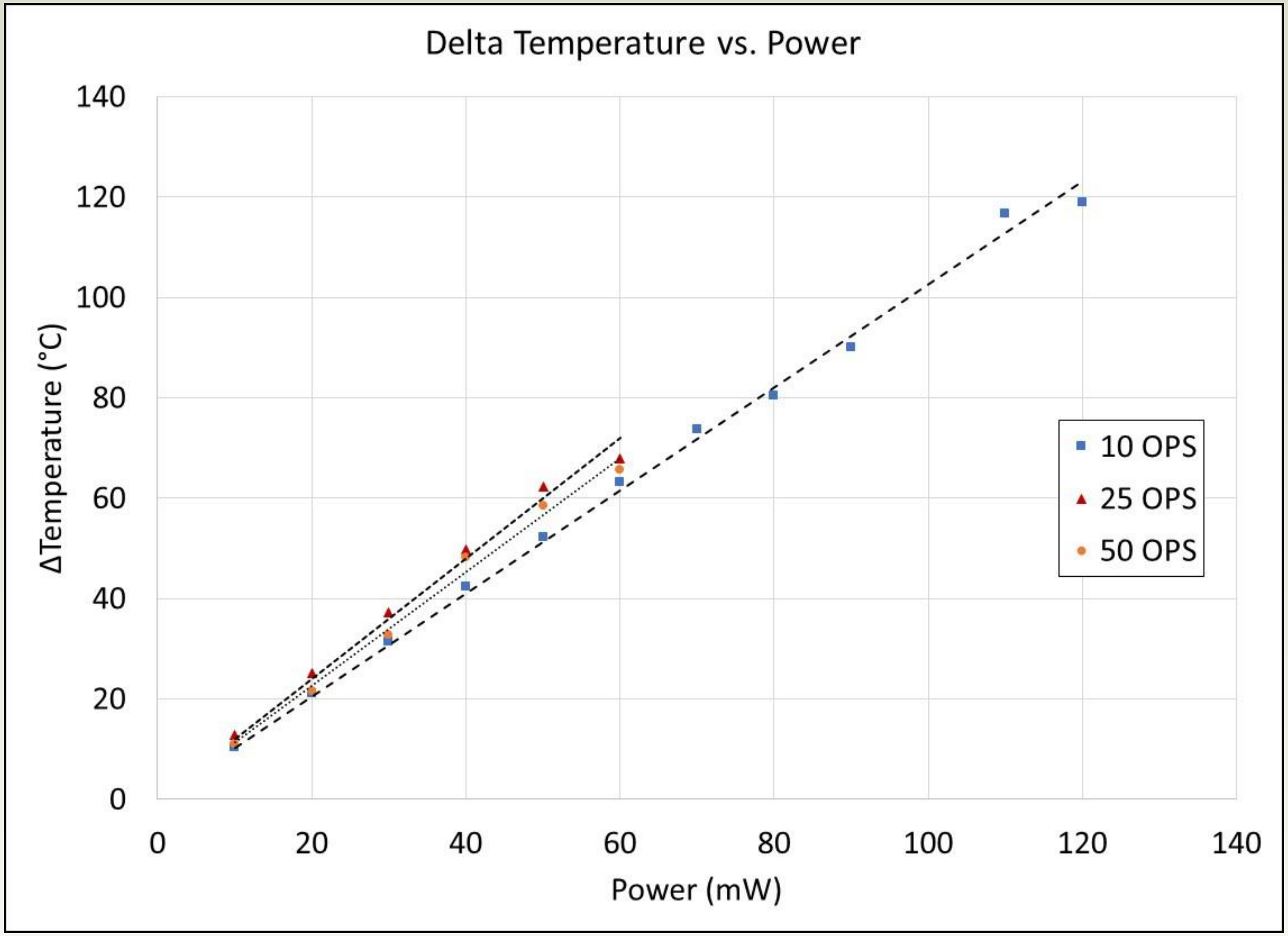


Temperature vs Power Data



PCB Carolina 2019

Temperature vs Power Data Summary Chart



PCB Carolina 2019

Study Summary

- NiP microheaters demonstrated good correlation between temperature rise and input power.
- The NiP microheaters required relatively low power and fast rise times to achieve maximum temperature.
- The temperature of the microheater was limited by the maximum operating temperature of the substrate and protective conformal coating over the resistors. Higher temperature resistant substrates (for instance, polyimide) and copper heatsink planes near the resistive elements will allow for higher power and temperatures.
- Applications using NiP as microheaters are now under development/pre-production in both MEMs PCBs and Lab-on-PCBs with excellent initial results.

Concept Application Illustration

NiP resistor as heater illustration

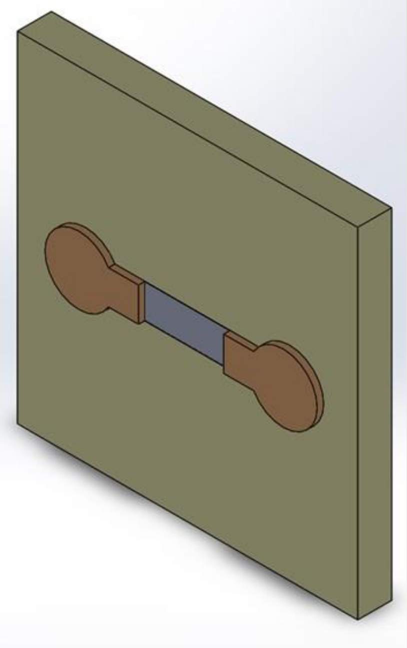


Illustration showing NiP resistor/heater on inner layer. Surface mount footprint with thermal conduit pad in center.

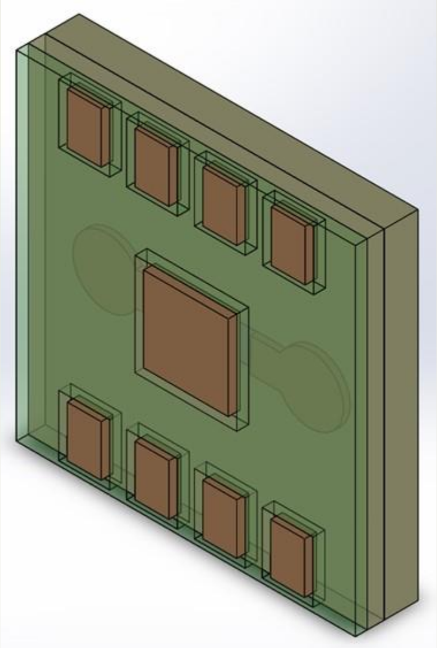
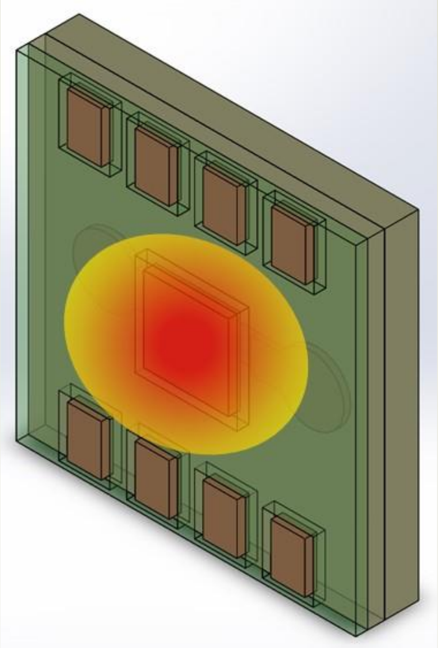


Illustration depicting heat flow on surface layer thermal pad from underlying NiP resistor/heater.



Concept Application Illustration

NiP resistor as heater illustration

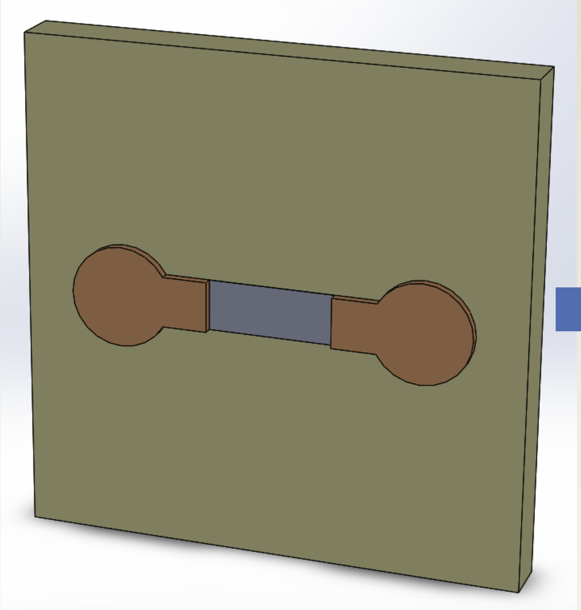


Illustration showing NiP resistor/heater on inner layer. Cavity with various channels.

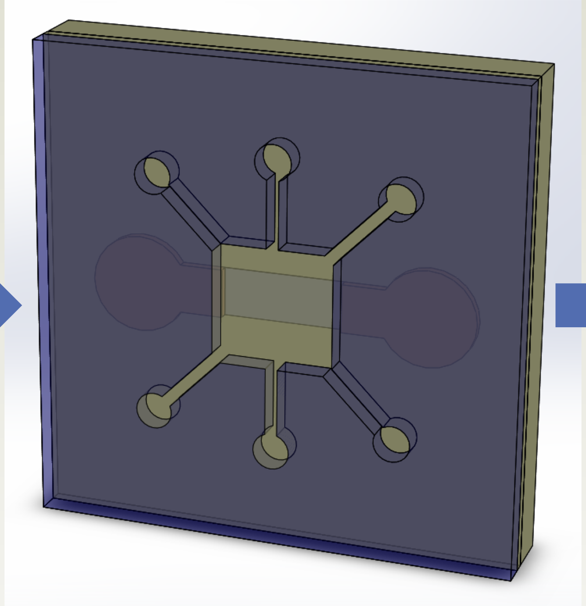
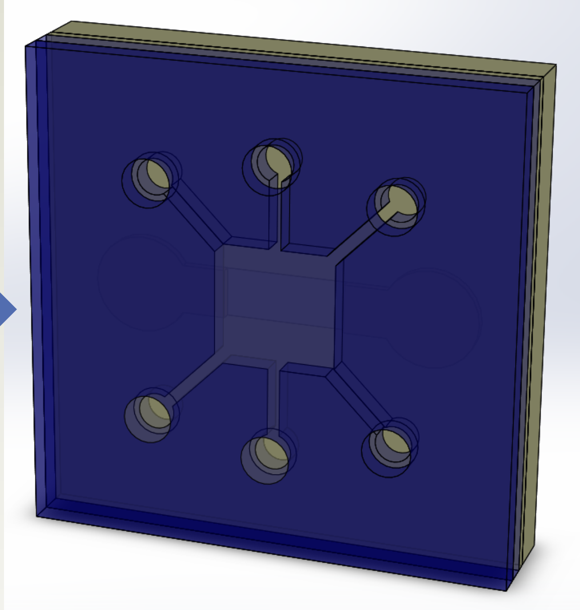
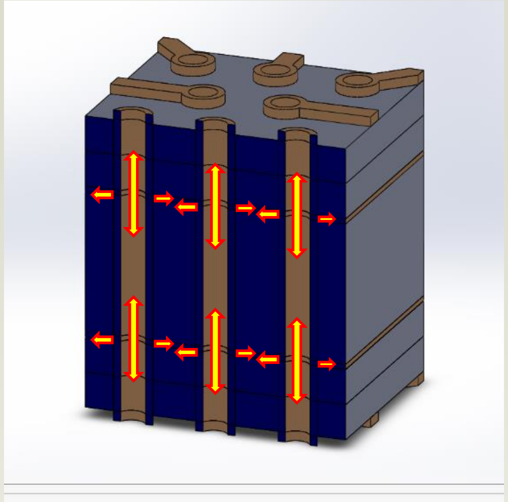


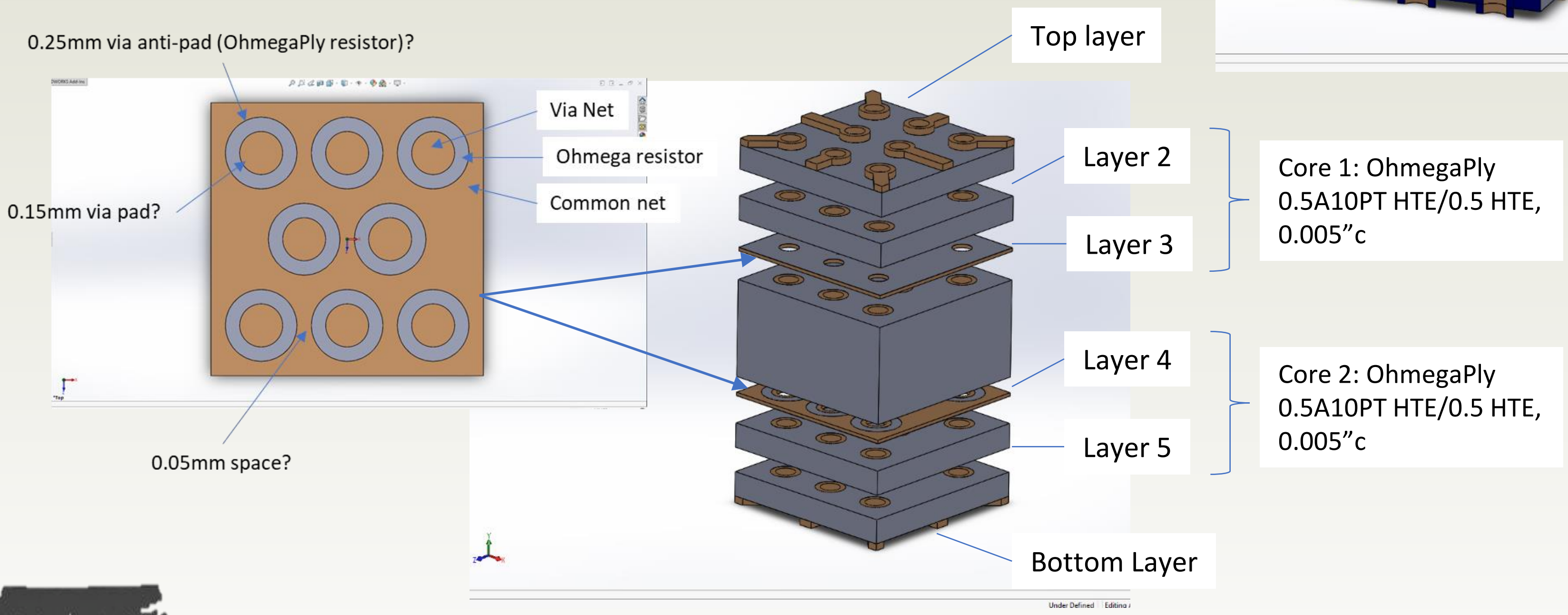
Illustration depicting enclosed cavity in PCB with various channel access ports.



Concept Application: Via in Pad Embedded Heater

- Concept illustrating technology versatility.
- Heat conducted through plated via directly to CSP solder balls.





PCB Carolina 2019

Embedded NiP Thin Film Resistors
Summary and Conclusions

- Standard Subtractive PWB Processing
- Surface or Embedded Resistors
- Mature Technology (45+ years)
- Increasing use in sensors, antennas, absorbers and in RF circuits, particularly in emerging 5G technologies
- Used extensively as heater elements in a wide variety of electronic applications

PCB Carolina 2019