MESOSCRIBE TECHNOLOGIES

MesoPlasma™ Printed Instrumentation for Extreme Environments

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www.mesoscribe.com

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At a Glance

NASDAQ: CVV

FOUNDED
1982

HEADQUARTERS
Central Islip, NY

NUMBER OF EMPLOYEES
~200

MESOSCRIBE TECHNOLOGIES

CVD Equipment Corporation is a leading deposition equipment and coating solutions supplier since 1982

"We provide turnkey equipment solutions, comprised of substrate handling, instrumentation, reactor geometry, process control software, gas management, and exhaust abatement.

In our materials division we provide deposition and coating services enabled by our innovation, unique capabilities, and the materials-driven demands and challenges of the markets we serve"

Market Drivers:

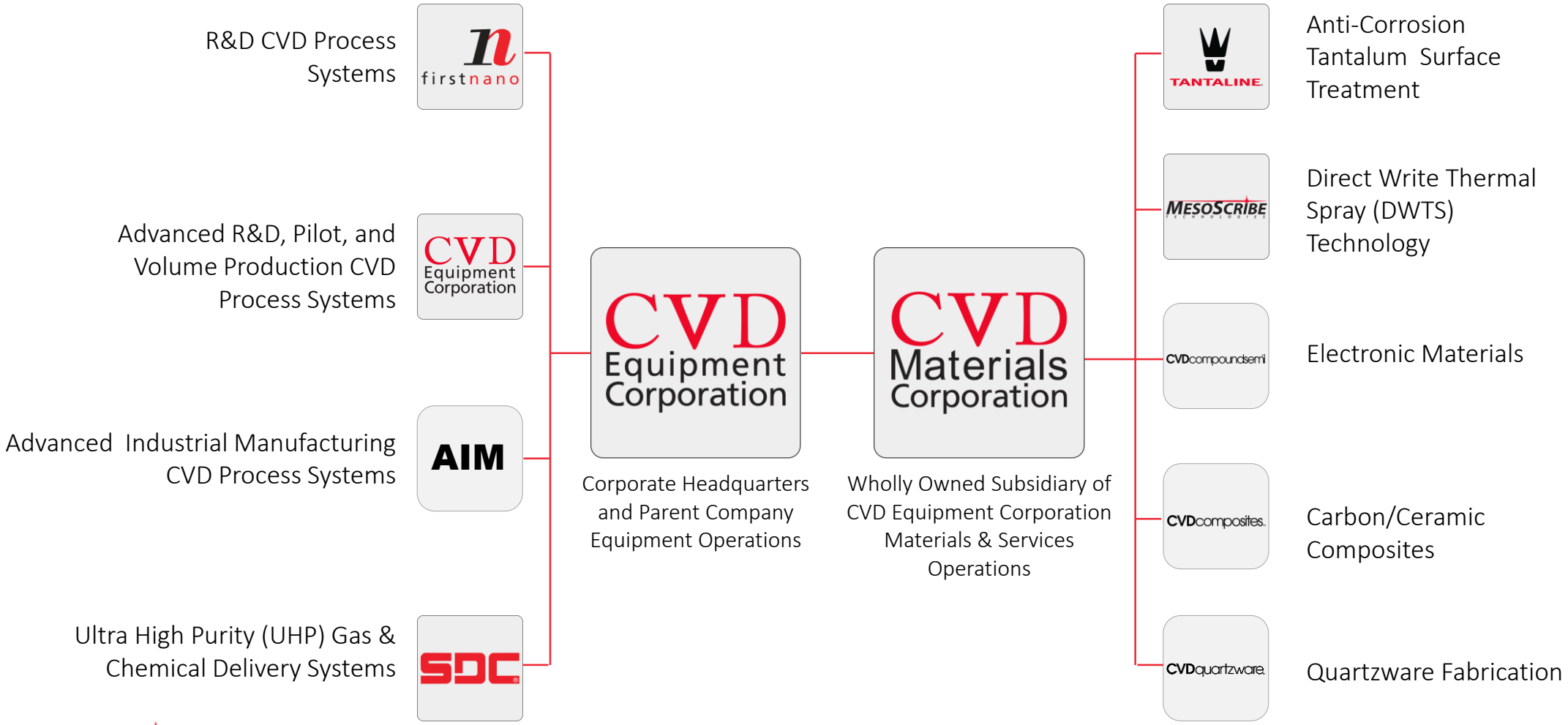
- ❑ High performance composite materials
- ❑ Additive manufacturing acceptance
- ❑ Energy efficiency of advanced electronic materials
- ❑ Medical devices driven by functional materials
- ❑ Nanotechnology used to improve all elements of life
- ❑ Defense and aerospace specialty materials

Keys to CVD's Value Proposition:

- ❑ Over 35 years providing Equipment and Process solutions
- ❑ Inhouse Process Development Laboratory
- ❑ Design Flexibility and Conceptual Modeling
- ❑ Proprietary Software and Control System Platform
- ❑ Scalable Manufacturing Capacity
- ❑ Vertically Integrated Manufacturing
- ❑ Direct Customer Engagement

EXPERIENCE. EQUIPMENT. MATERIAL SERVICES.

Our Company, Products, and Services



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MesoScribe™ - Printed Electronics

MesoScribe Technologies provides high performance products using proprietary MesoPlasma™ Direct Write Technology. Sensors, heaters and antennas are deposited onto conformal parts for demanding applications.

- Aerospace

  MesoScribe Technologies manufactures printed instrumentation for use on a production aircraft. The technology is an FAA approved manufacturing process.

- Power Generation

  Sensors are printed onto customer-supplied assemblies and gas turbine engine components to support engine testing, diagnostics, and component health monitoring.

- Satellite

  High watt density heaters are applied to both large and small satellite components. Heaters can be applied to complex geometries and provide up to 500W/cm^2.

- US Department of Defense

  MesoScribe Technologies supports the US Department of Defense by working with Government laboratory, Prime Contractors, and Subcontractors to develop innovative solutions to challenging problems.

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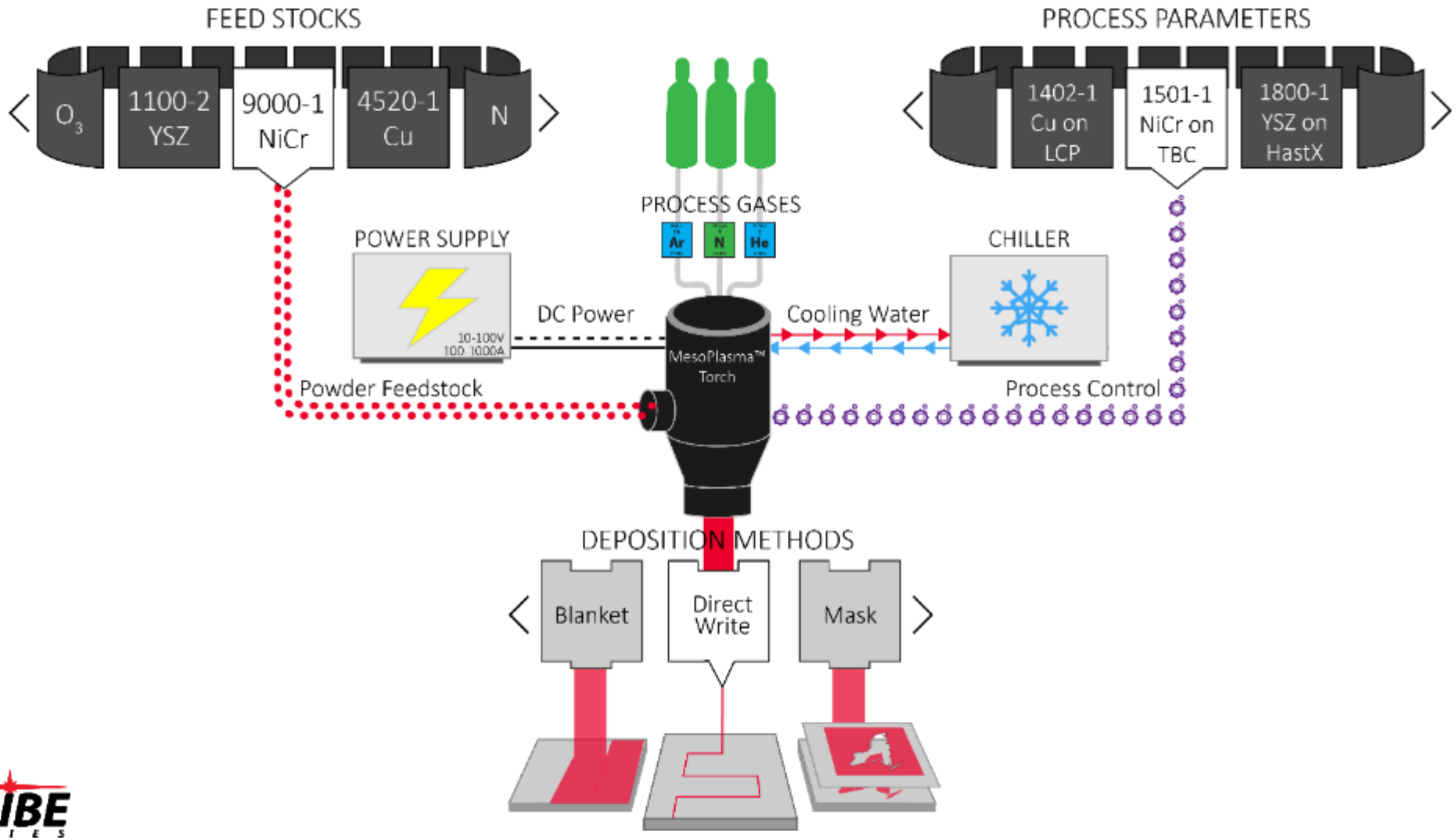
MesoPlasma™ Process Overview



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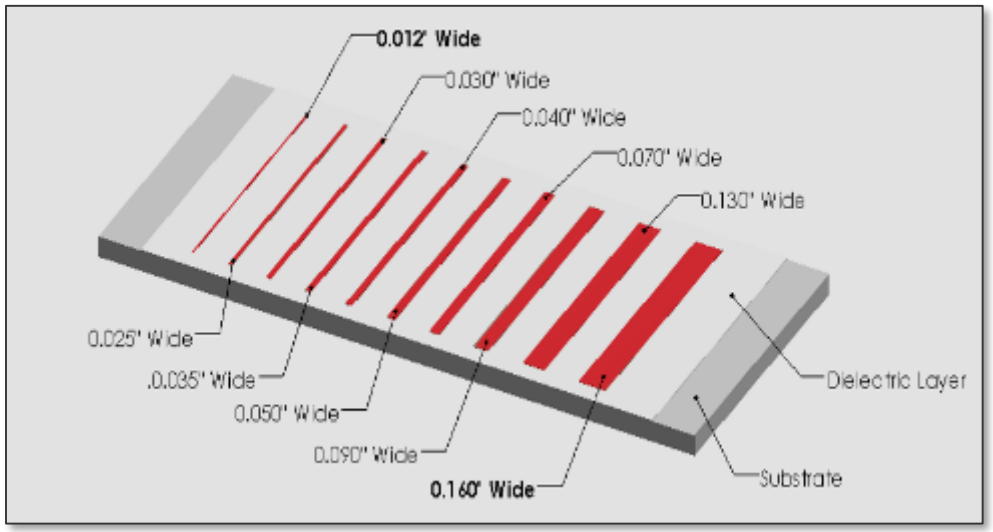
Printing Capabilities – Feature Sizes

STANDARD PRINTED TRACES

- Resolution: trace widths range from approx. 0.010” to 0.160”
- Thickness: Typically > 0.001”
- Direct Write offers the **most conformal** capable process

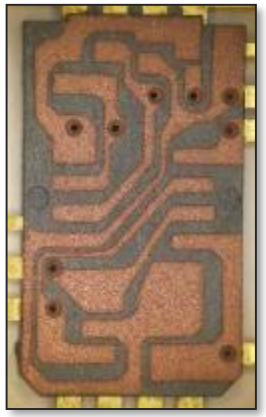


COMPLEX PATTERNING ONTO CONTOURED PARTS

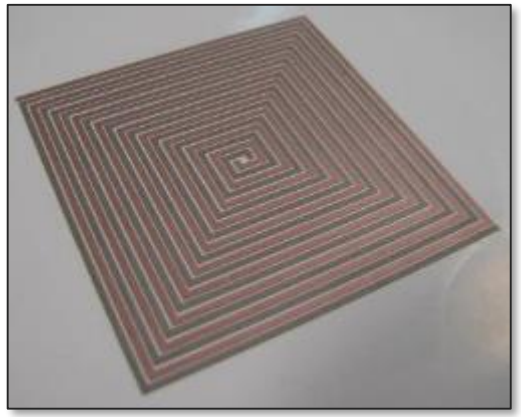
- Minimum feature sizes = 0.020” traces and islands (0.010” possible)
- Maximum feature sizes almost unlimited

Discrete RF Patterning (±0.002” tolerance band)

Metalization on LCP (0.7” x 0.4”)



Interdigitated Spiral (8” x 8”)



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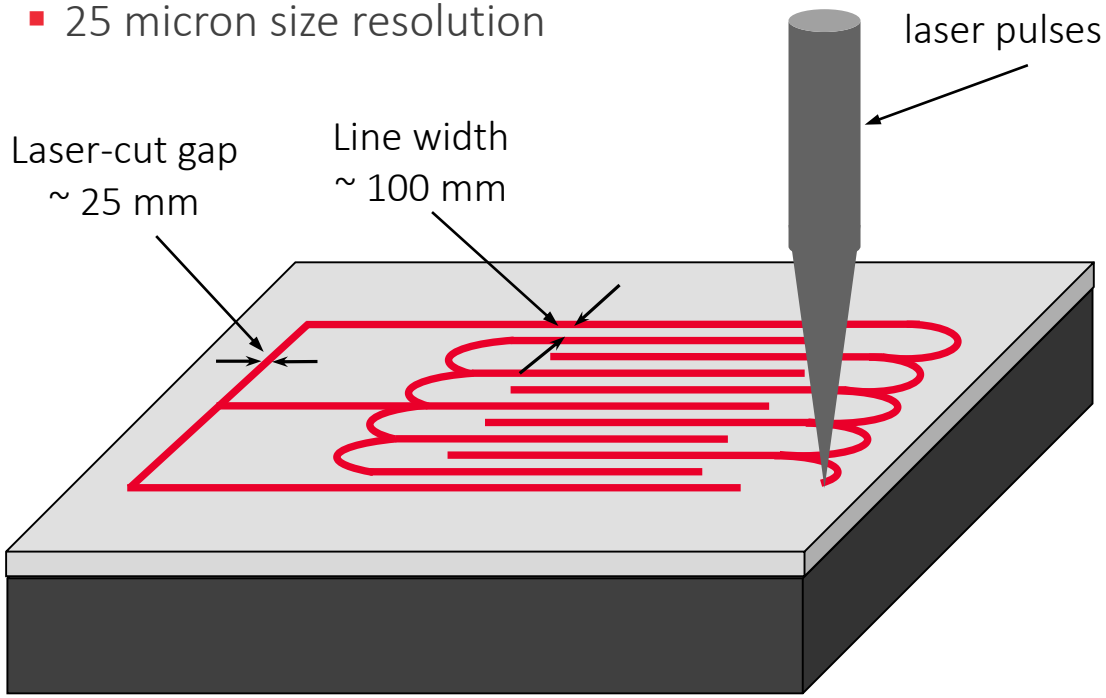
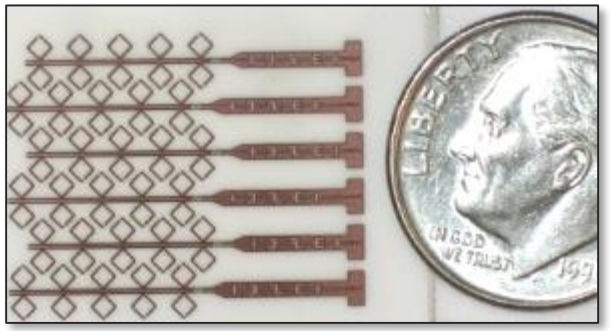
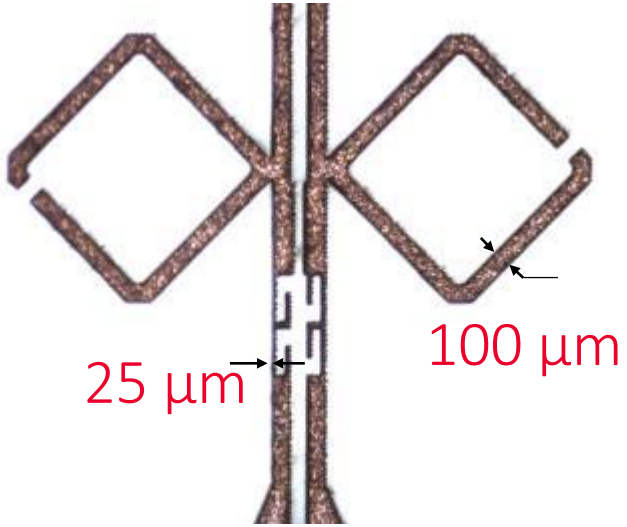
Producing Higher Resolution Features

- Combine MesoPlasma™ Printing with Laser Micromachining (additive-subtractive processing)
- Precision multilayer patterns
  - 25 micron size resolution



US Patent 7,709,766





Printed and Laser Processed

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Printing Capabilities - Materials

BROAD FEEDSTOCK LIBRARY

- Conductors
  Cu, Ni, Pt, Pd, Ag
- Sensor Alloys
  NiCr, NiAl, NiSil, NiCrSil, CuNi
  NiCrAlY, FeNi
- Dielectrics
  Al_2O_3, $MgAl_2O_4$, YSZ, proprietary materials
- Custom Alloy Compositions
  Available upon request

BROAD SUBSTRATE COMPATIBILITY

- Most Metals
  - ✓ Aluminum, Copper, Steels, Superalloys, Titanium, etc.
- Many Polymers
  - ✓ LCP, Polyimides, Ultem, PEEK, Tedlar
- Other Materials
  - ✓ CMC, Carbon Composites, Fiberglass, 3D Printed materials
- Dielectric Layer
  - ✓ Needed for conductive substrates
  - ✓ Typically ceramic coating for metal substrates and high-solids paint for low temperature substrates

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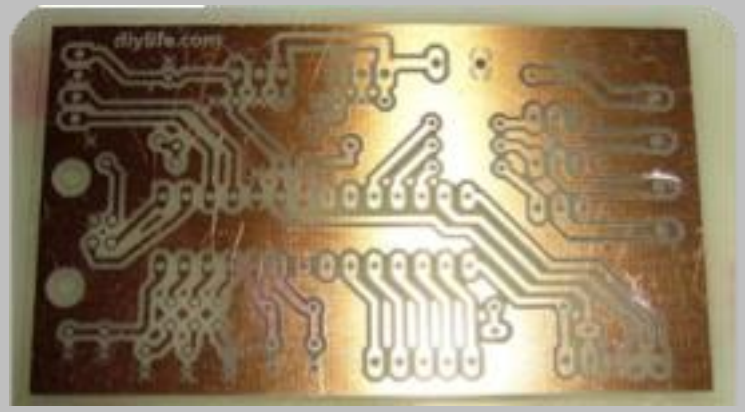
Benefits of Direct Write/ Digital Printing

Traditional Electronics

Plate entire surface with one material then remove unwanted material



- Flat, stiff substrates (occasionally flexible)
- Limited materials, copper only
- Requires masking and hazardous etching materials

MesoPlasma™ Printing

Deposit only the material needed, where it is needed

- Complex, curved parts of most any material
- Many material choices (metals, alloys, semiconductors, ceramics)
- No masking, no etching

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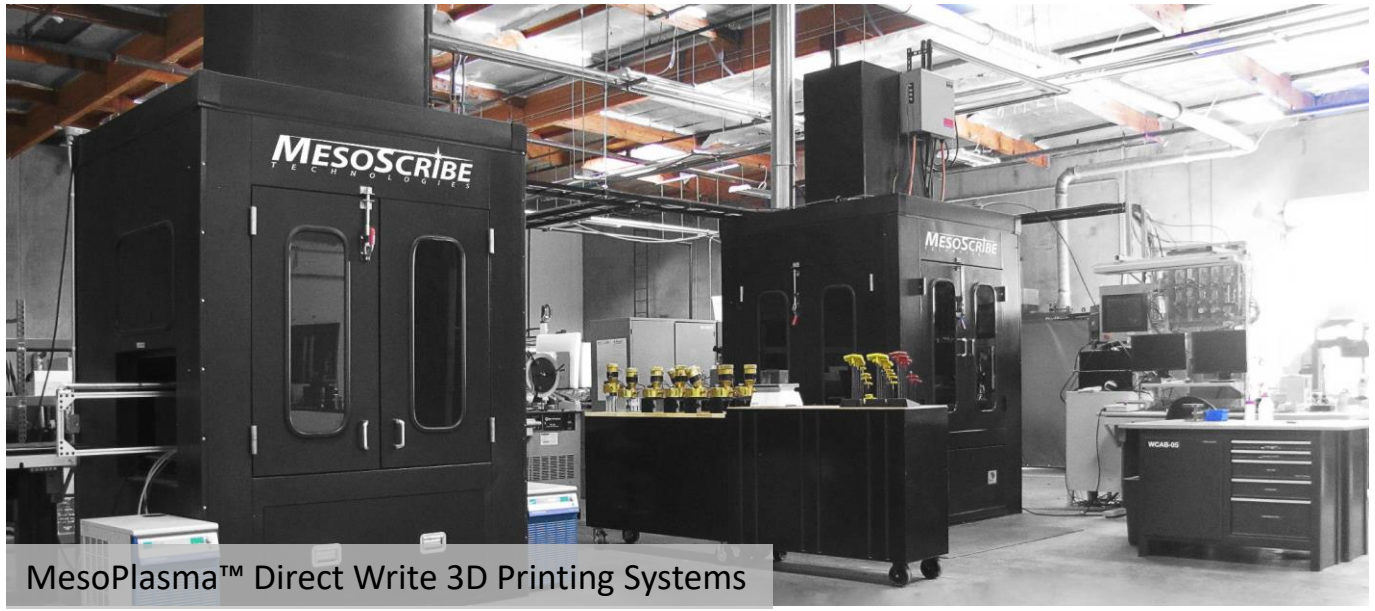
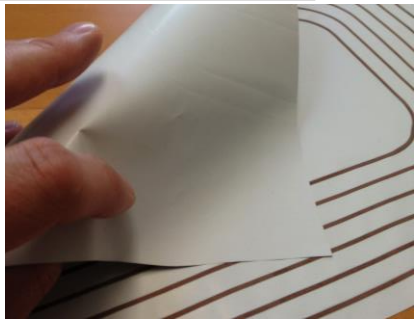
MesoScribe™ – Current Aerospace Applications

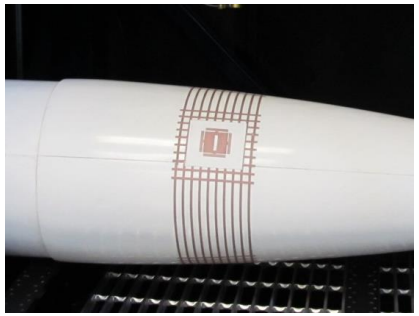


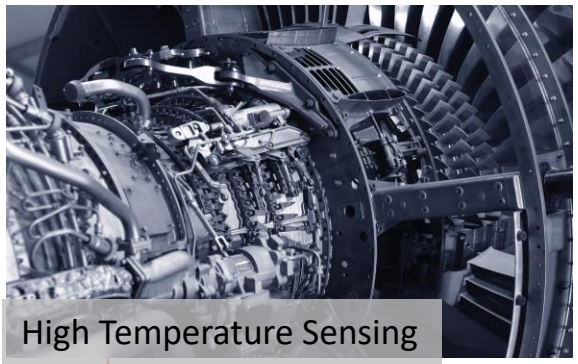
MesoPlasma™ Direct Write 3D Printing Systems

Embedded Sensing



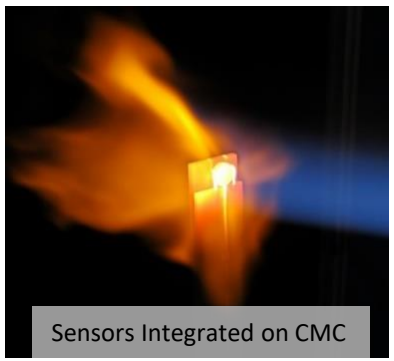
Conformal Antennas





High Temperature Sensing

Printed TC



Sensors Integrated on CMC

High Power Heaters

- Integration onto Superalloy and CMC Materials

- Sensor products are used in commercial aircraft
- Antennas integrated into UAV structures
- Heaters qualified for flight hardware/satellites

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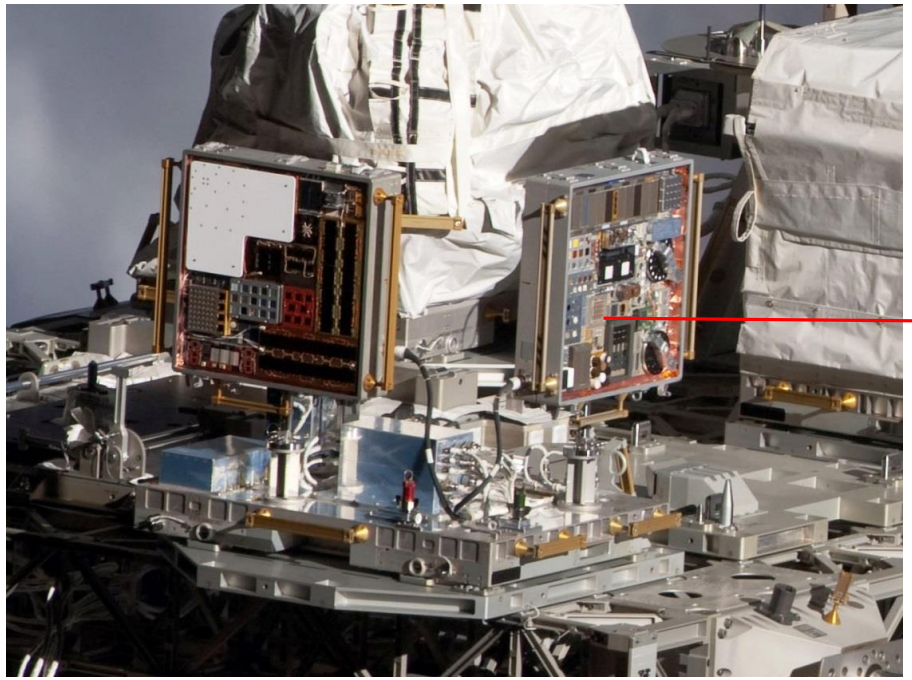
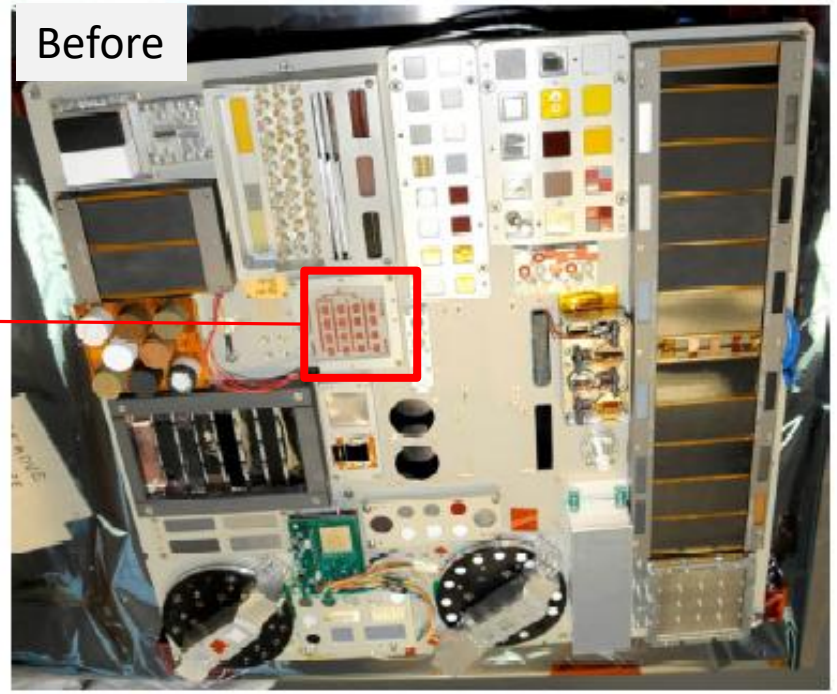
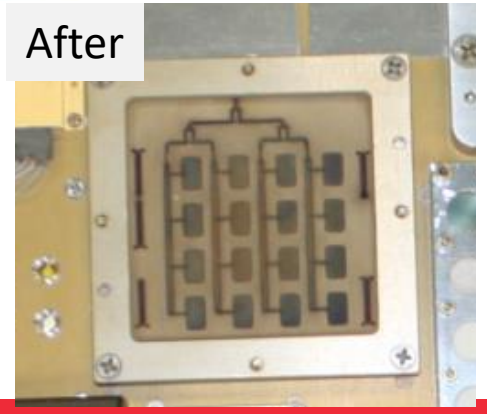
In support of Boeing - MISSE 7





- MesoScribe printed a 4x4 patch array, 15GHz antenna for MISSE-7 (Materials International Space Station Experiment–7).
- Antenna orbited on the Space Station from October 2009 to September 2011.



- No cracking
- No spallation
- Surface discoloration only

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Video: Strain-Tolerant Conductors

MesoPlasma™ Printed Copper Traces Exhibit Exceptional Strain and Fatigue tolerance

- Printed onto polymer films, fiberglass composites
- Strain Level: > 5,000 micro-strain
- Minimal changes in electrical resistance after millions of cycles

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Commercial Aerospace Product

MesoPlasma™ printed electronics– from idea to airplane in under 3 years!

MesoScribe™ provides printed instrumentation to a major aircraft manufacturer for use on a production aircraft

- FAA approved manufacturing process
- Delivered > 2,000 products

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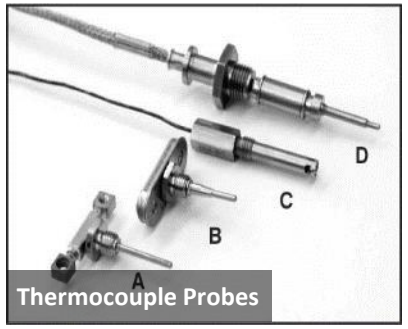
Why Embedded Sensors?

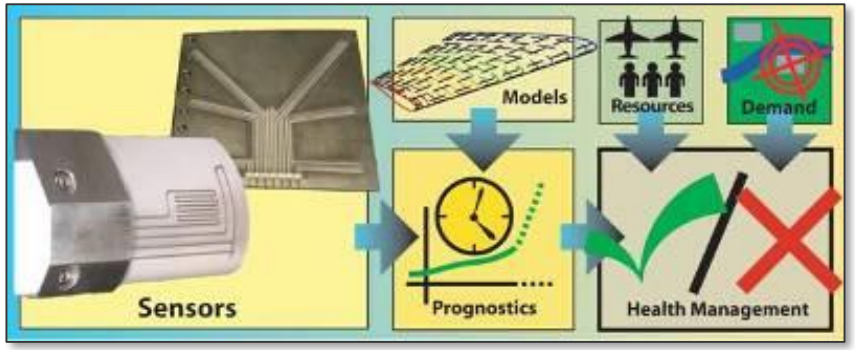
- Conventional sensors are difficult to attach to complex part geometries
  - Protruding sensor can disrupt flow
  - Failures with adhesive, lacks durability
  - Brazing requires destructive part trenching
- Coatings can provide a platform to integrate a printed sensor
  - Use of compatible materials
- Produce “Smart Components”
  - Knowledge of materials
  - Knowledge of component
  - Knowledge of environment



Thermocouple Probes


Thermocouple Wire


Cracked Turbine Blade



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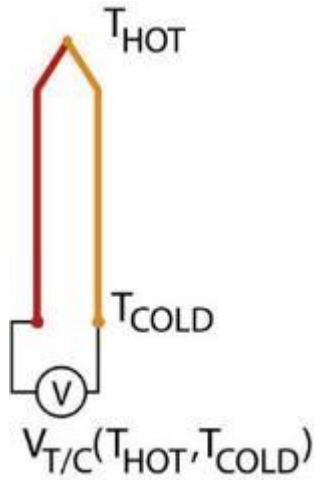
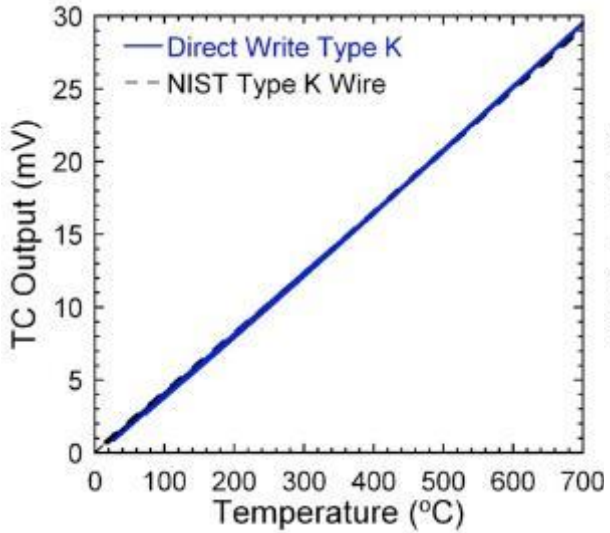
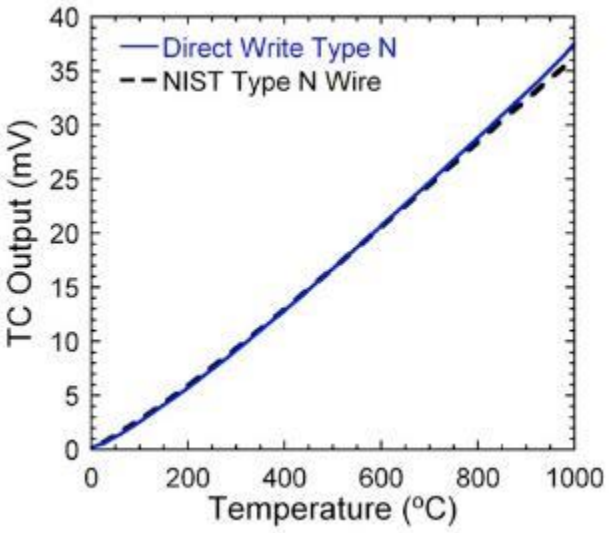
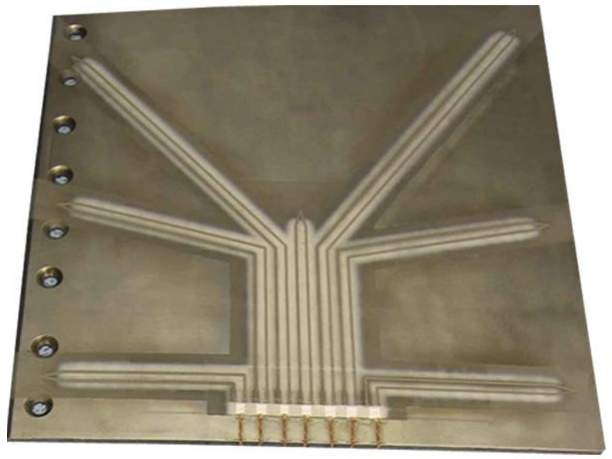
Printed Thermocouples (TCs)

- Passive devices that provide measurements of **component temperature**
  - Standard NIST designations (Types T, E, K, N)
  - Precious metal (Pt-Pd) TCs for use at elevated temperatures > 800°C
- Thermocouple traces routed to desired location for welded wire attachment (or integration with wireless transmitter)





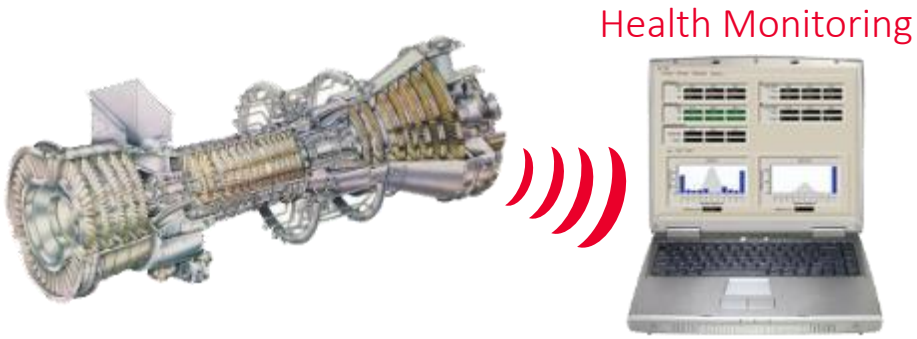


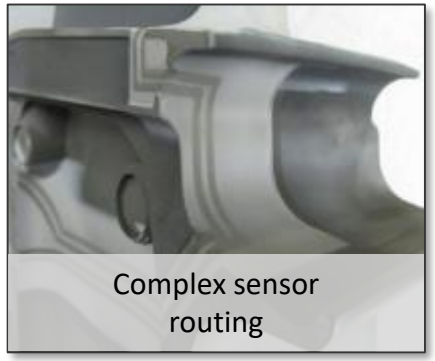


Distributed TC Arrays

Gas Turbine Engine Instrumentation

- Key Market Drivers
  - Printed sensors onto engine components for diagnostics to support engine development
  - Structural health monitoring, failure prediction, & Prognostics
- Advantages
  - Automated, repeatable sensor installation
  - Conformal sensor routing to enable lead wire attachment at lower temperature (extending sensor life)
  - Can be embedded within thermal barrier coating (TBC)
    - 800°C with Type K/N
    - 1000°C+ with Pt/Pd




Complex sensor routing


Instrumented blade with TCs

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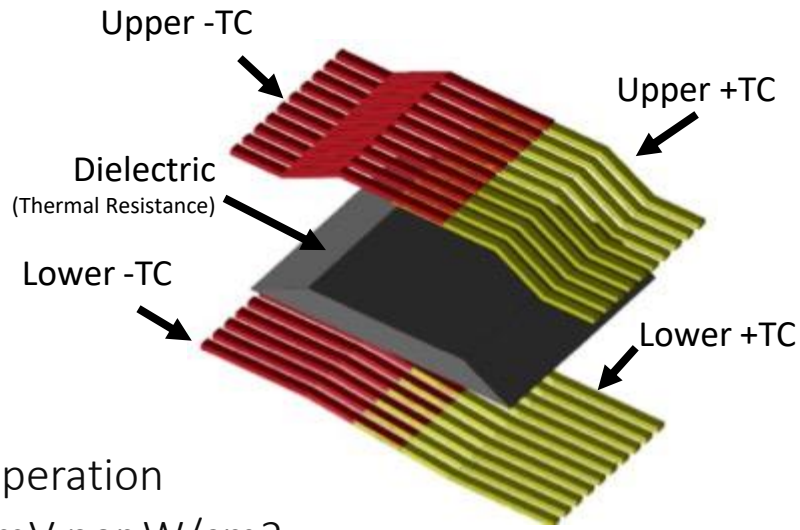
Heat Flux Sensors

- Differential thermopile, linear voltage response to heat flux
- Printed onto part or provided as a stand-alone sensor



- Benefits
  - Low profile design
  - No water cooling
  - High temperature
  - No adhesive/carrier limitations
  - High sensitivity
  - Custom sizes
- Specifications
  - High Temperature: 800°C operation
  - High Sensitivity: 0.2 to 1.0 mV per W/cm2
  - High spatial resolution and custom sizing
  - Response Time: < 100ms (63.2%)
  - Low profile: Less than 0.02” (0.5mm)

- 110 Series

- 202 Series

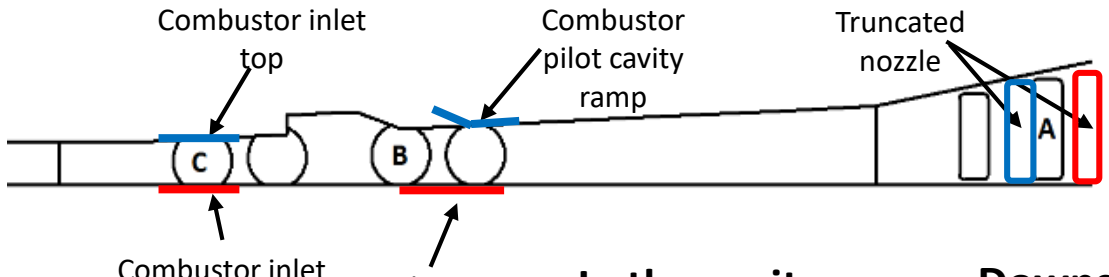
- 131 Series

- High Temperature Use

3 Model 141 sensors on a US dime

Hypersonic Scramjet Engine Instrumentation

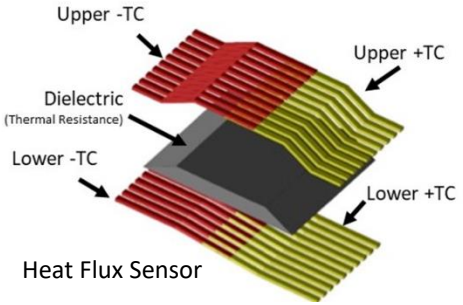
- MesoScribe's Heat Flux gauges are Used in USAF Hypersonic Scramjet Engine Development
  - Demonstrated at AFRL/RQHF direct connect tunnel test
  - Mach 5 flow, 1,650°C gas temperature
  - Provides measurement of transients

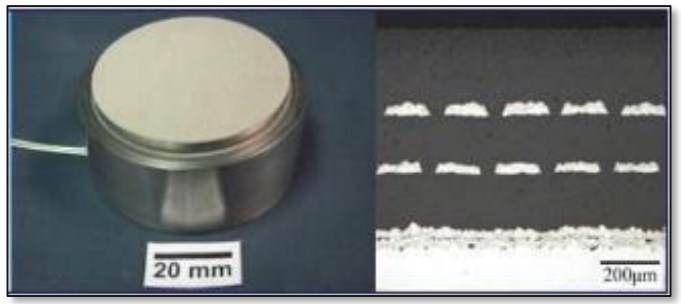


Upstream
200 – 600 kW/m²

In the cavity
600 – 2000 kW/m²

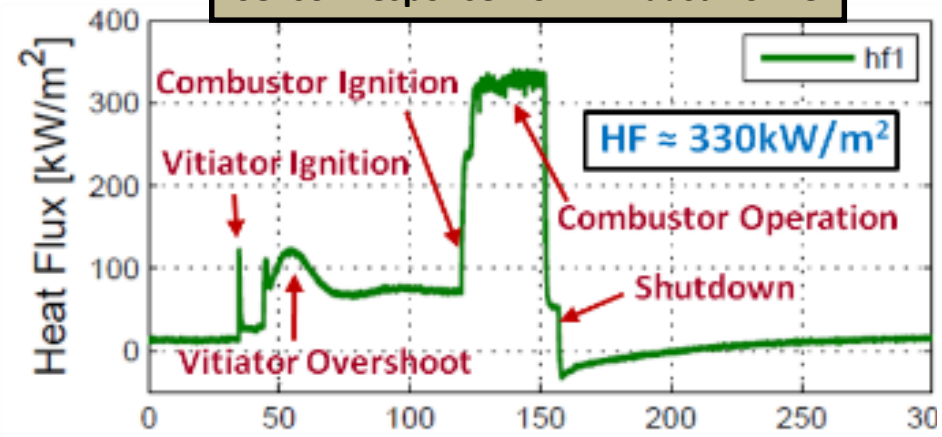
Downstream
400 – 1000 kW/m²



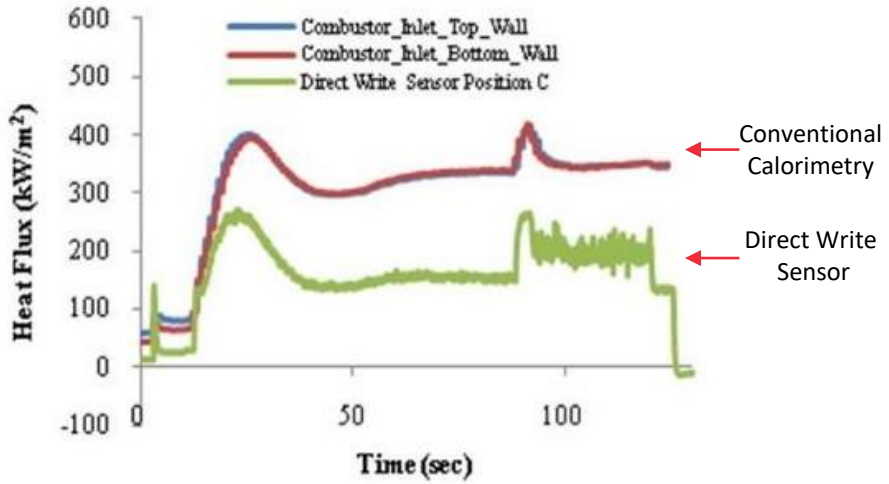


- Heat Flux Sensor embedded within ceramic coating
- Successfully measured transients compared to conventional calorimetry
- More accurate HF response, no water cooling required

Sensor Response from Exhaust Nozzle



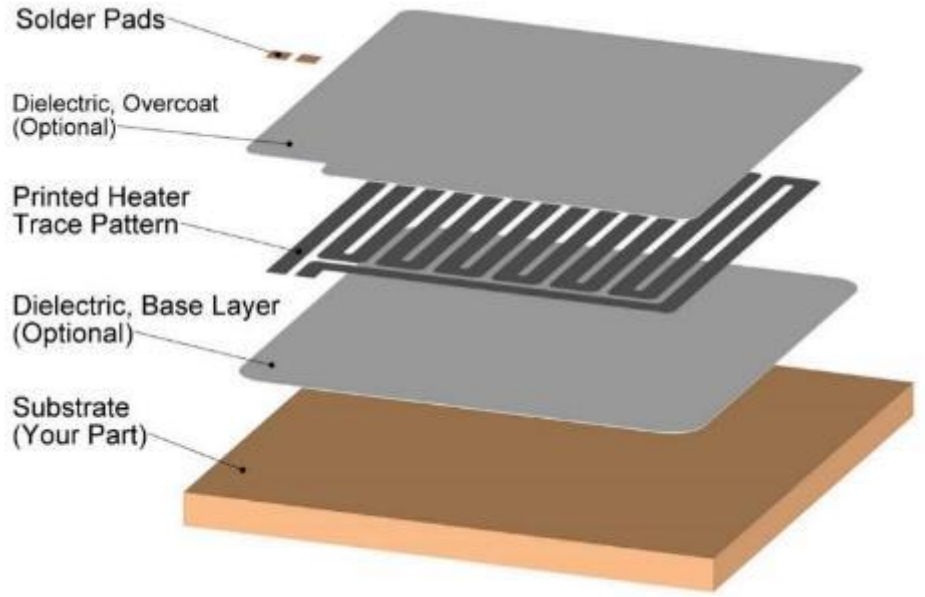
Sensor Response from Combustor Inlet



Printed Heaters

MesoScribe™ Advantages

- Heaters Printed Directly on Your Parts
  - No adhesive required
    - High temperature capability
    - Reduce or eliminate installation costs
    - Increase system reliability
  - Can be applied to complex 3-D geometries
  - Compatible with most substrate materials
    - Metallic, ceramic, polymer
  - Custom patterning and uniformity
- High Heat Flux Capability
  - Up to 500W/cm^2 for many heaters
  - Demonstrated to >1000W/cm^2
- Robust & Durable
  - Thermal shock resistant
    - -200°C to +200 °C



- Applications
  - Satellite Heating
  - Fuel Lines
  - Semiconductor Tools
  - Industrial Process Equipment
  - Medical Devices
  - Test Equipment

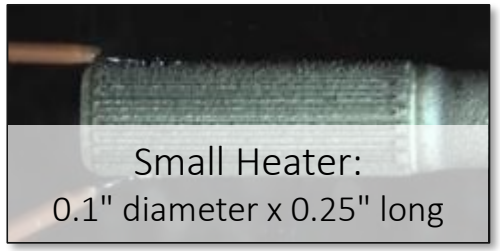
Printed 8-Zone NiCr Heater

MESOSCRIBE TECHNOLOGIES

Printed Heaters

Micro Heaters

Square mm Area
1 to 50 OHMS

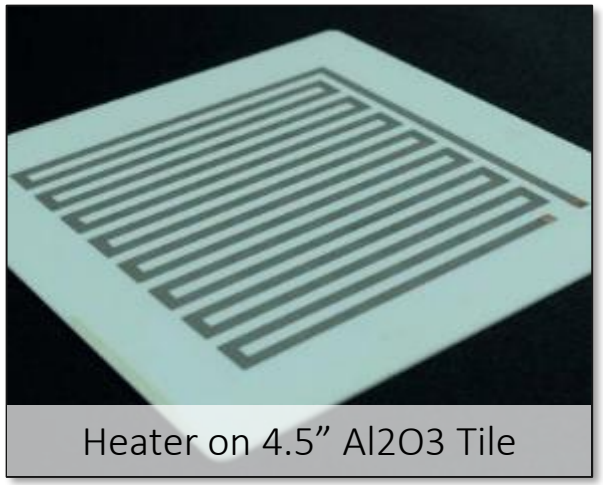


Small Heater:
0.1" diameter x 0.25" long

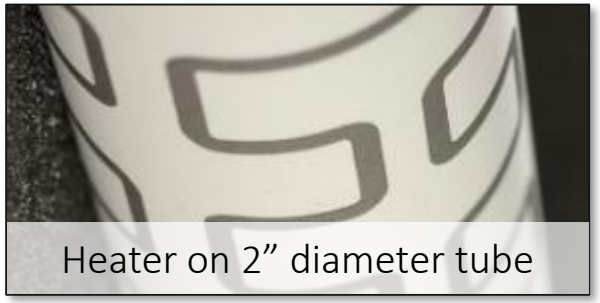
Small Heater:
7Mmm X 7mm

Standard Heaters

Square Inch Area
2 to 500 OHMS



Heater on 4.5” Al2O3 Tile



Heater on 2” diameter tube

Large Area Heaters

Square Feet Area
10 to 1000+ OHMS

Heater on 12” x 12” FR4

Large Heater 12” diameter

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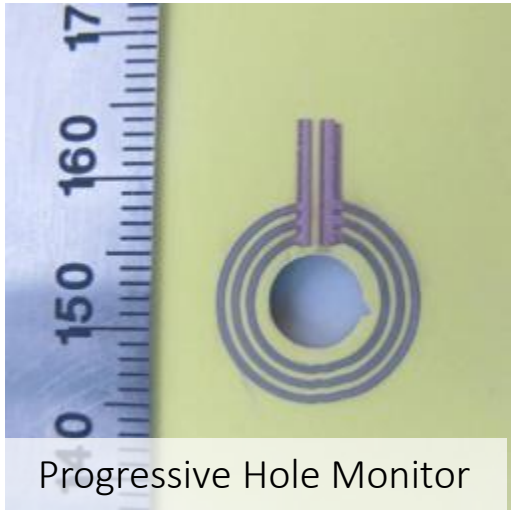
Crack Detection

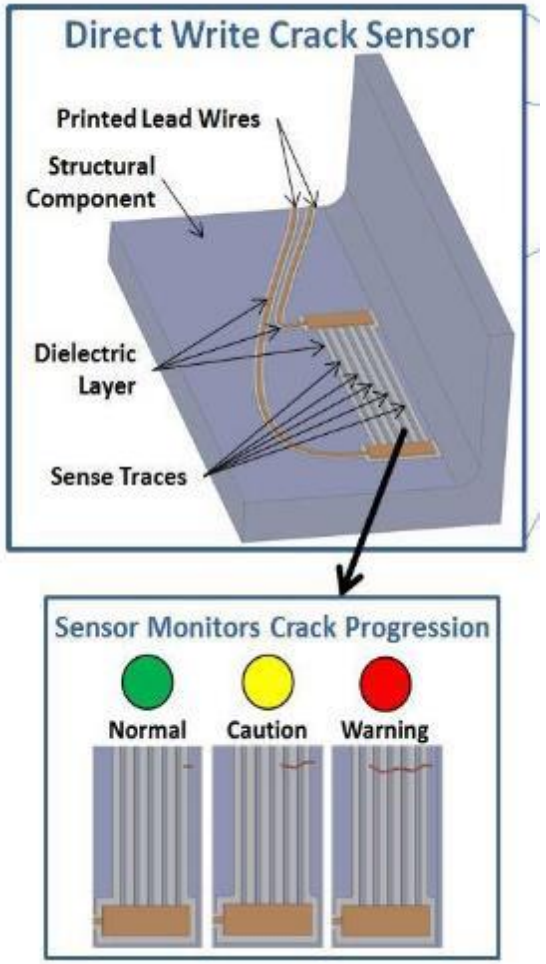
- Sensor traces are printed directly onto component in precise patterns
- Cracking is detected through changes in electrical resistance
- Patterns can be customized for desired response
- Compatible with most component materials

Simple Open Circuit



Progressive Hole Monitor

Crack Length Detection



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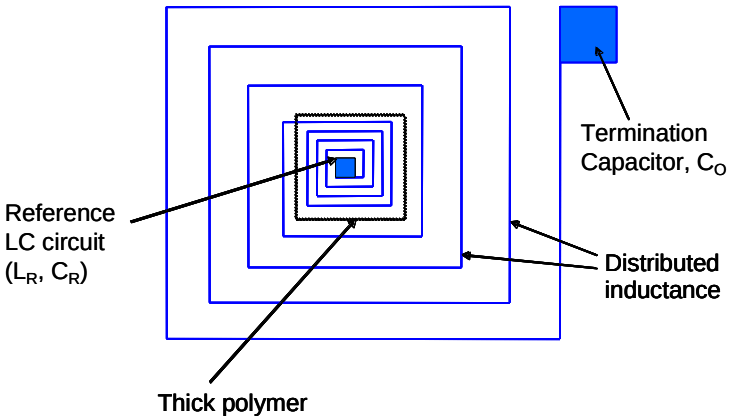
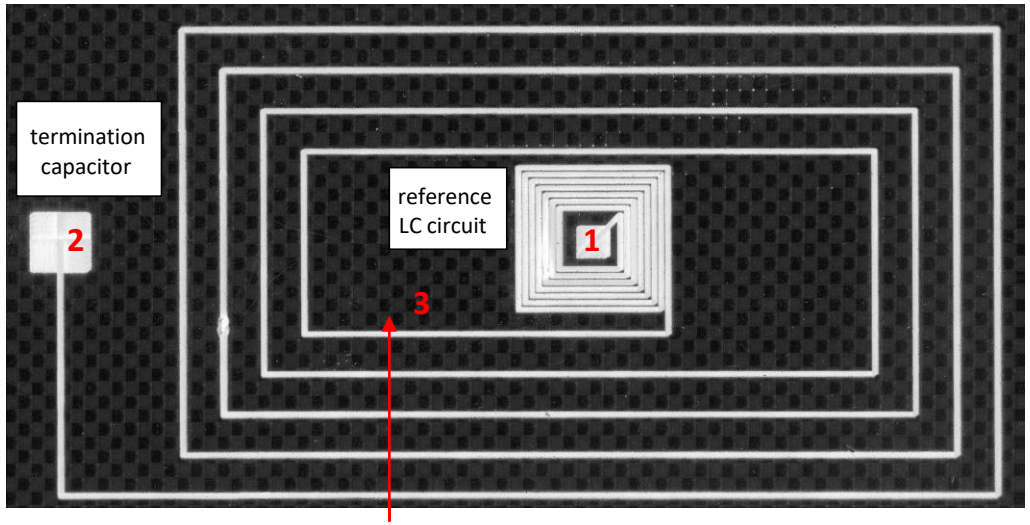
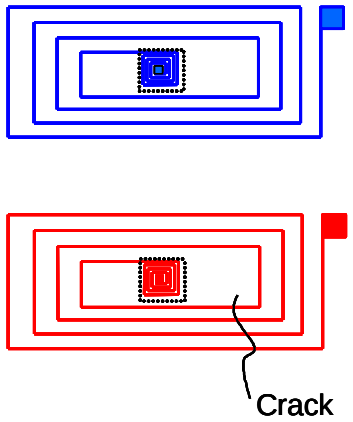
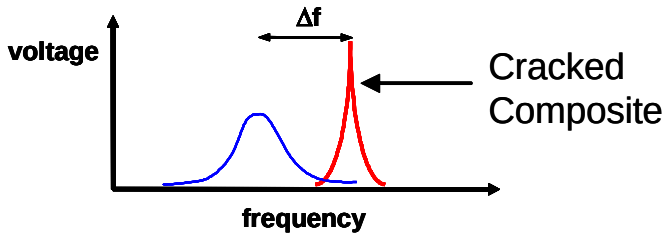
Crack Detection in Gr/E

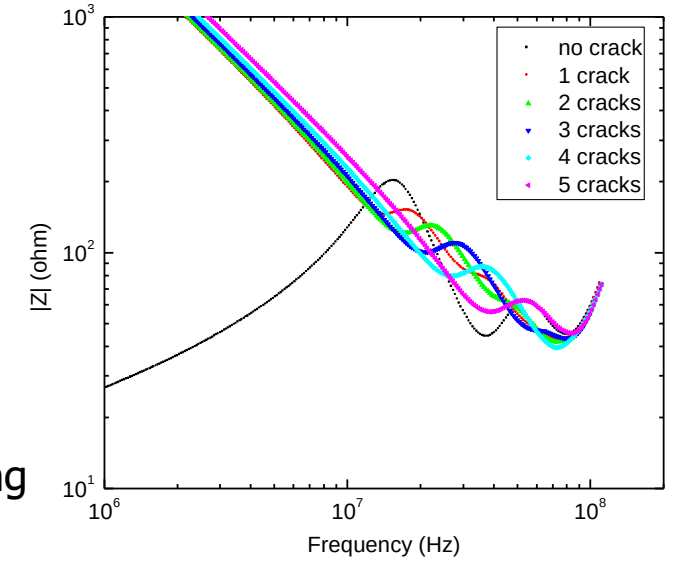








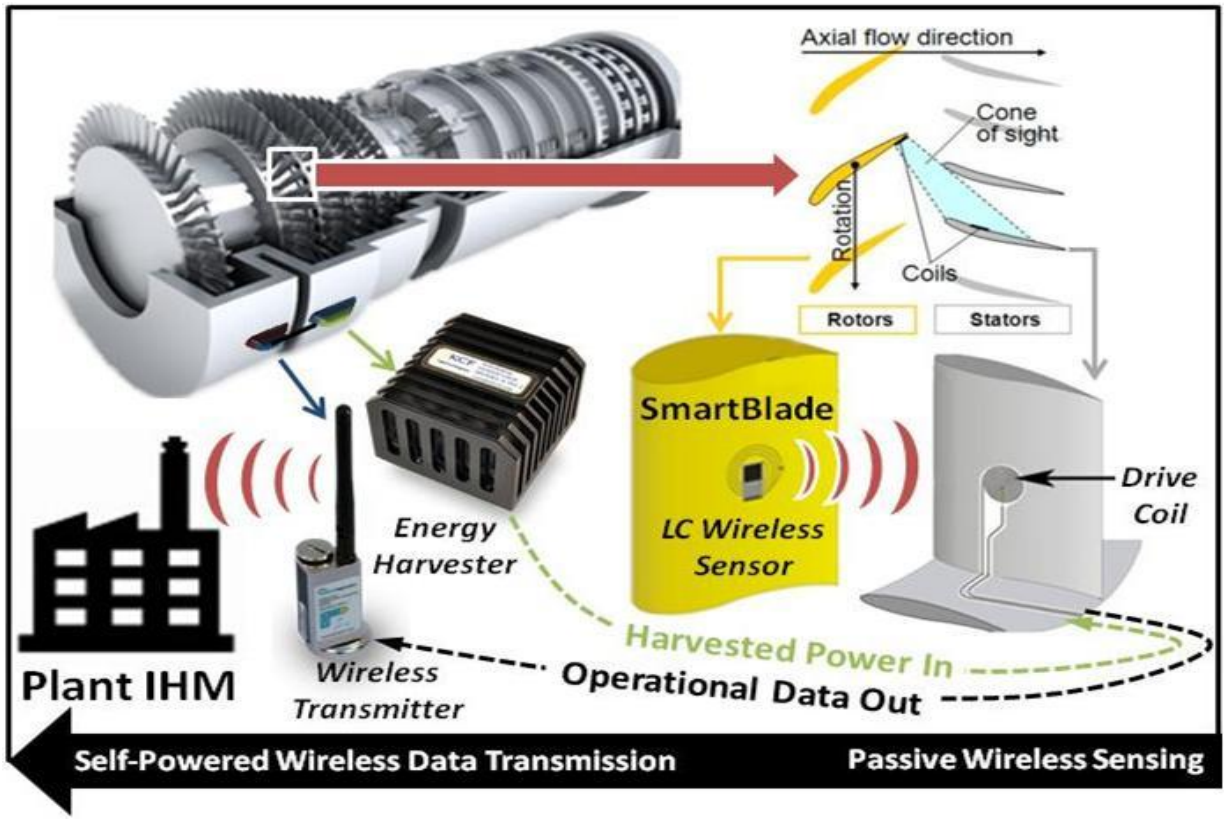
Cracked
Composite



Frequency characteristics
Detectably altered due to cracking

MESOSCRIBE TECHNOLOGIES

Motivation to Develop MesoPlasma™ Printed Passive Wireless Sensors

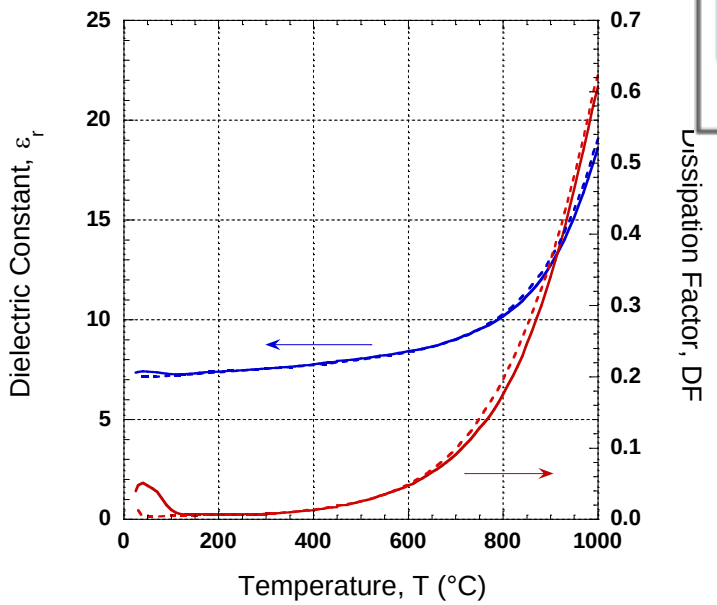


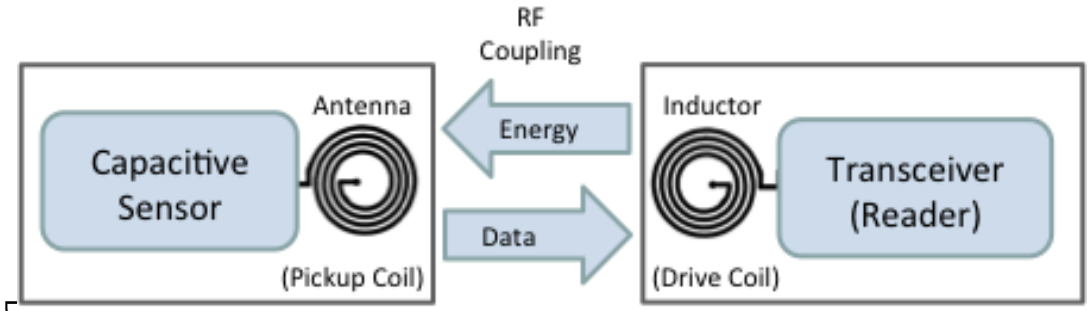
- Develop passive wireless interrogation technique to measure temperature of rotating components to 1000°C
- Test LC sensors in relevant environments (combustion spin test) to advance TRL

Prior DOE SBIR Phase II Grant No. DE-SC0006207, MesoScribe Technologies, Inc.

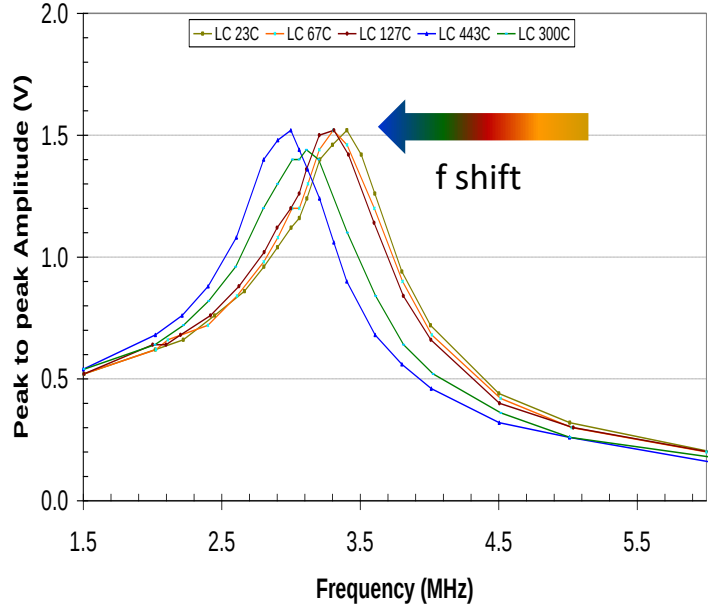
Passive Wireless Temperature Sensing

- Printed sensor is powered by a remote reader, which sends out an oscillating magnetic field across the printed drive coil/inductor
- Sensor capacitance is a function of temperature, shifting resonant frequency as monitored on drive coil





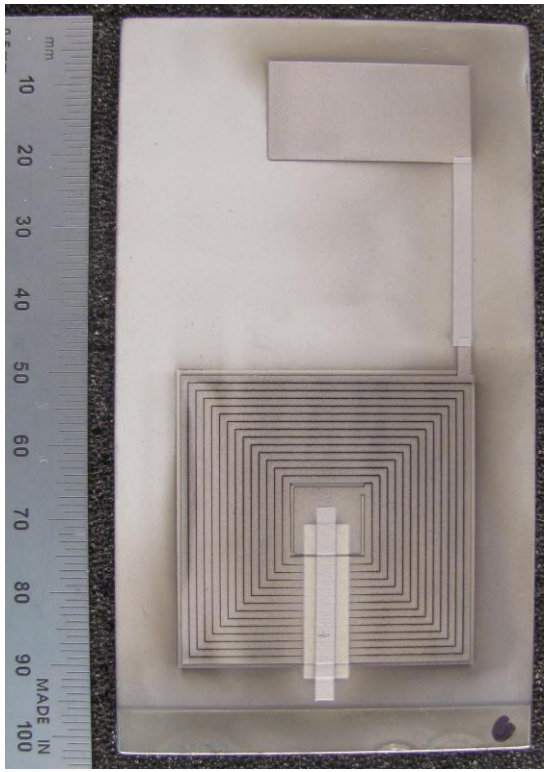
- During RF interrogation, an impedance loading on the signal occurs at a specific characteristic frequency that is correlated to the temperature of the sensor
- As temperature of the sensor increases, the resonance frequency will decrease



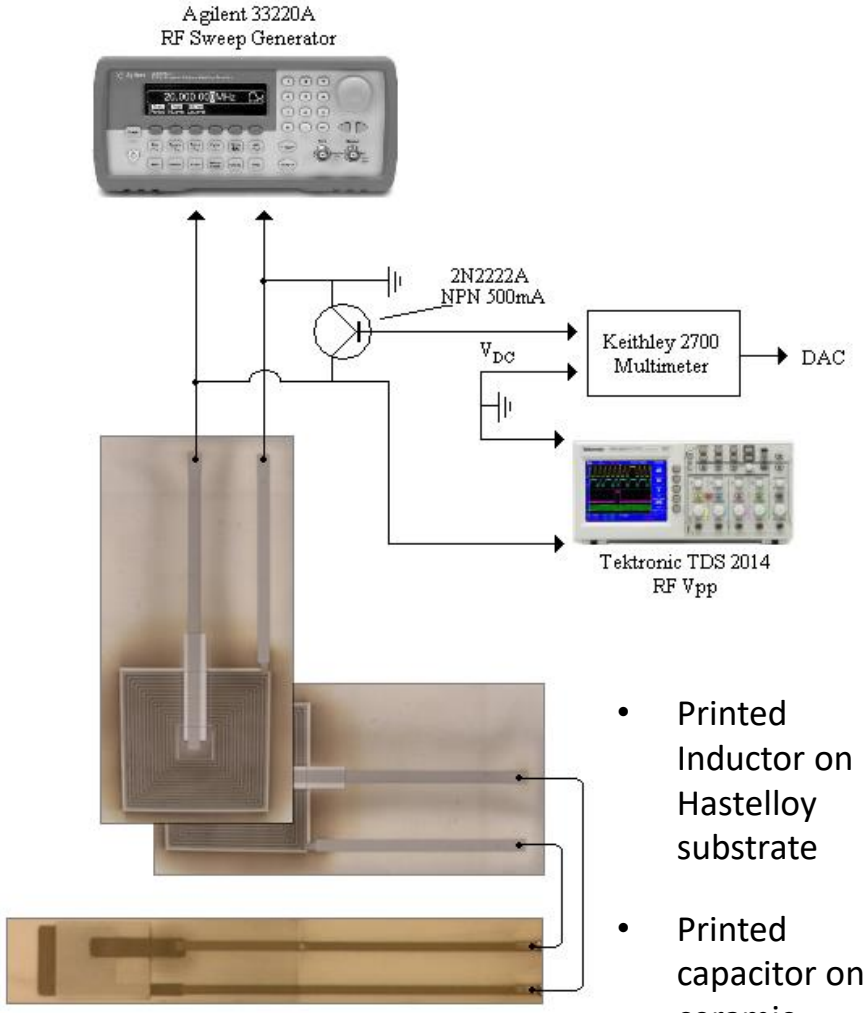
Prior DOE SBIR Phase II Grant No. DE-SC0006207, MesoScribe Technologies, Inc.

Passive Wireless Temperature Sensor

- Wireless temperature sensor is an LC circuit
- Sensor is interrogated by excitation coil, another inductor in close proximity
- The frequency of the excitation is swept through the resonance frequency of the LC sensor circuit



- Printed palladium inductor coil and temperature-sensitive capacitor

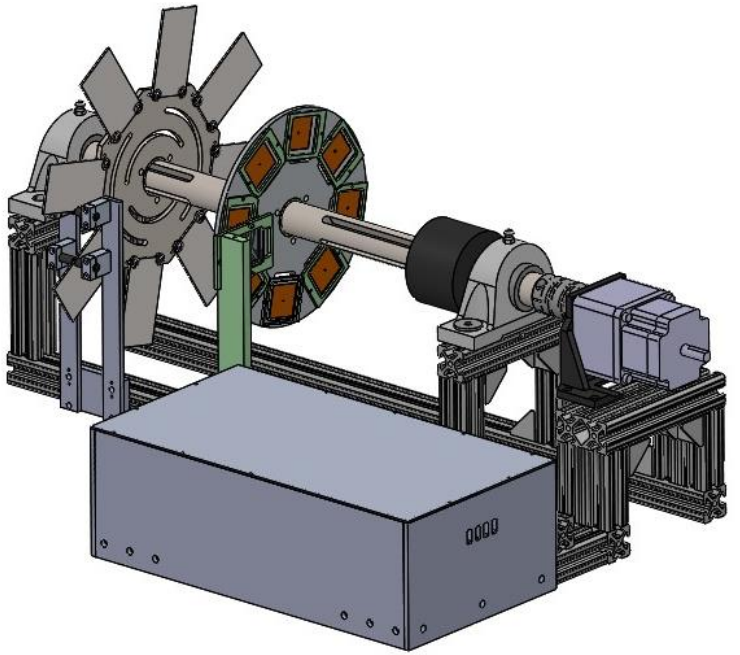


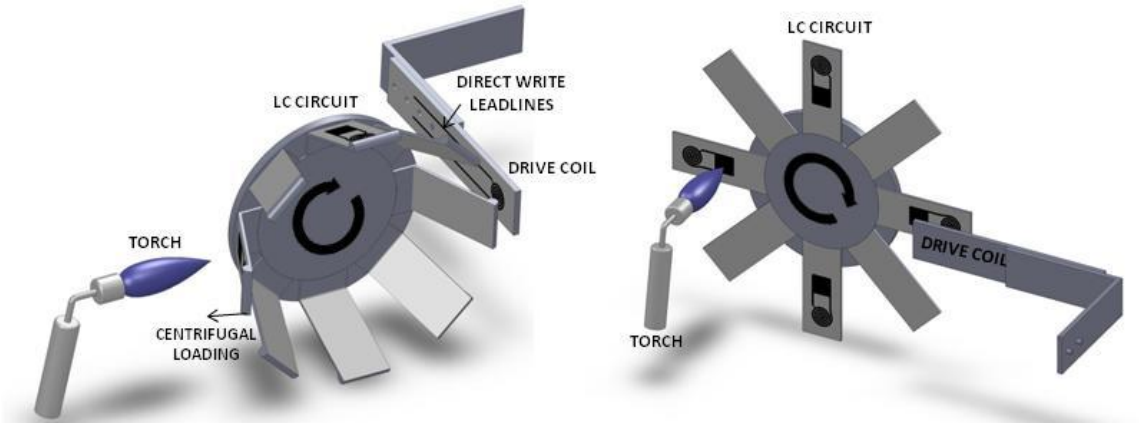
- Printed Inductor on Hastelloy substrate
- Printed capacitor on ceramic substrate

Prior DOE SBIR Phase II Grant No. DE-SC0006207, MesoScribe Technologies, Inc.

Demonstration: Rotating Spin Tester

- Spin Tester built to develop and demonstrate wireless sensing concepts in combustion environments
- Optical sensor gate to initiate timer trigger off of the edge of rotating sensor
- Trigger sends a signal to the interrogator to initiate the sweep
- Software locates resonant frequency through 5 frequency sweeps
- Temporal proximity of the drive/pickup coil determined within 1 ms
- Achieve positional overlap of the drive/pickup coil to within 100 microns at 15 RPM





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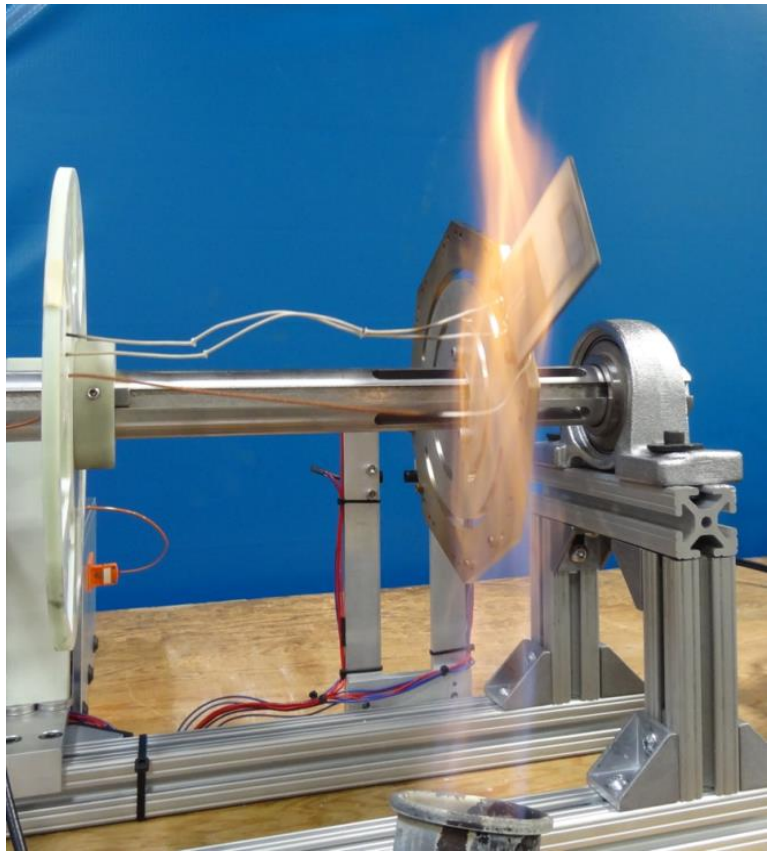
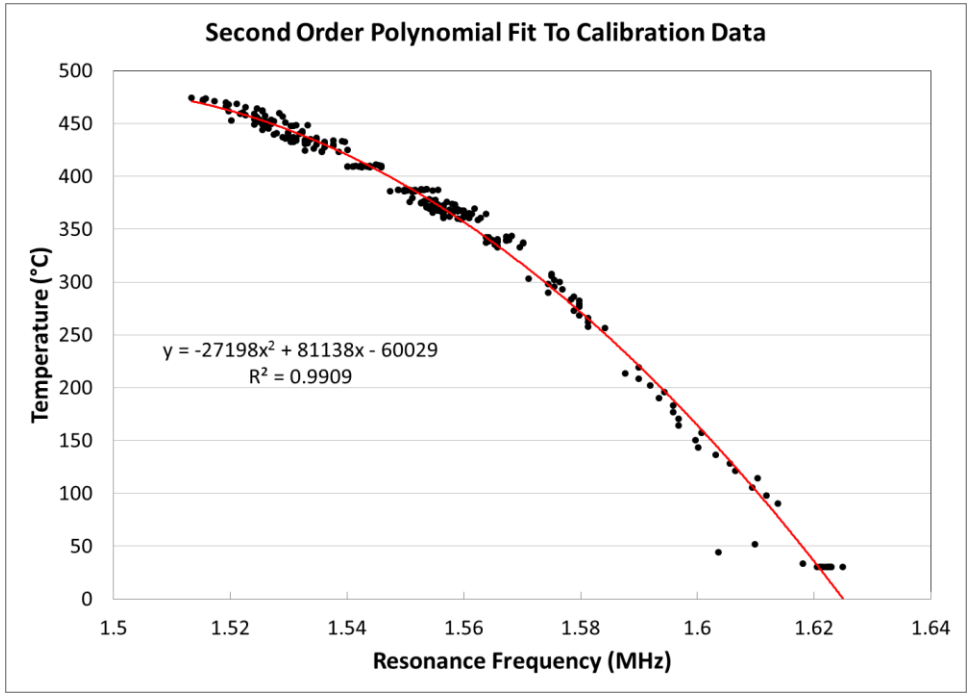
LC Temperature Sensor Calibration

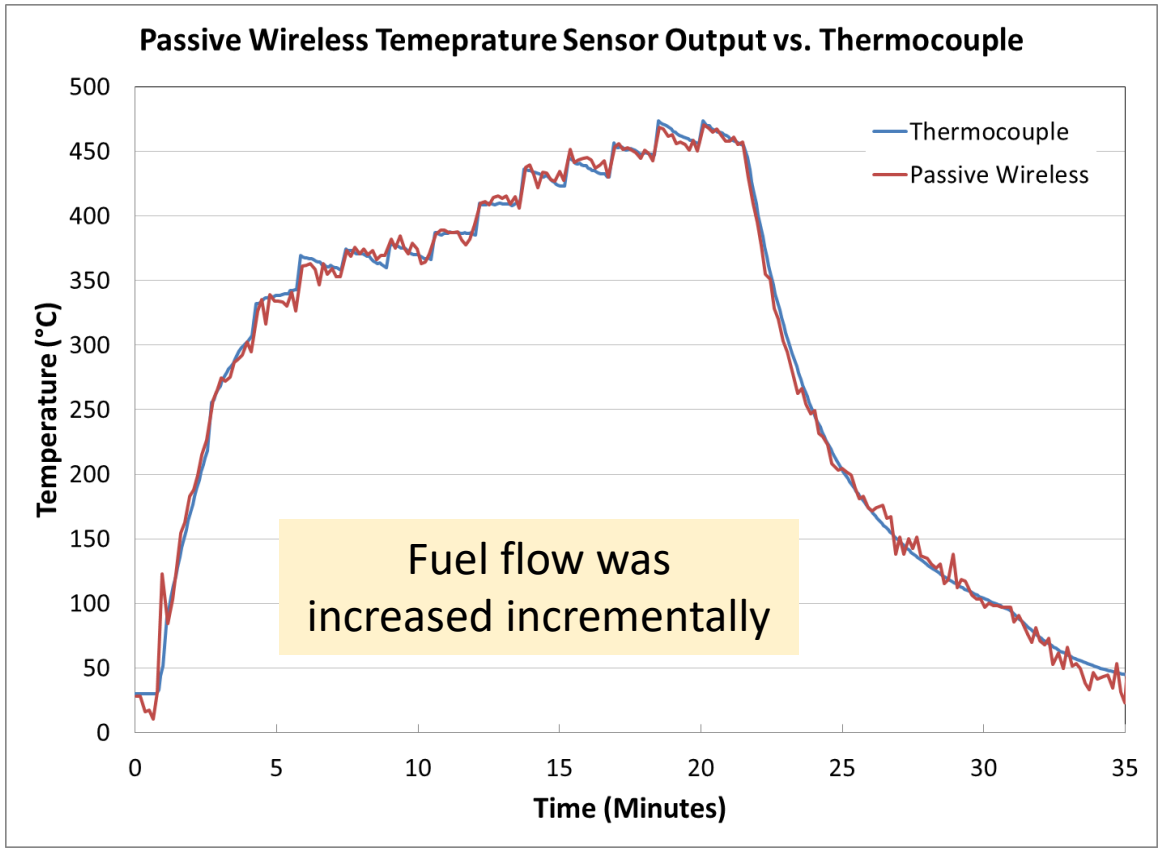


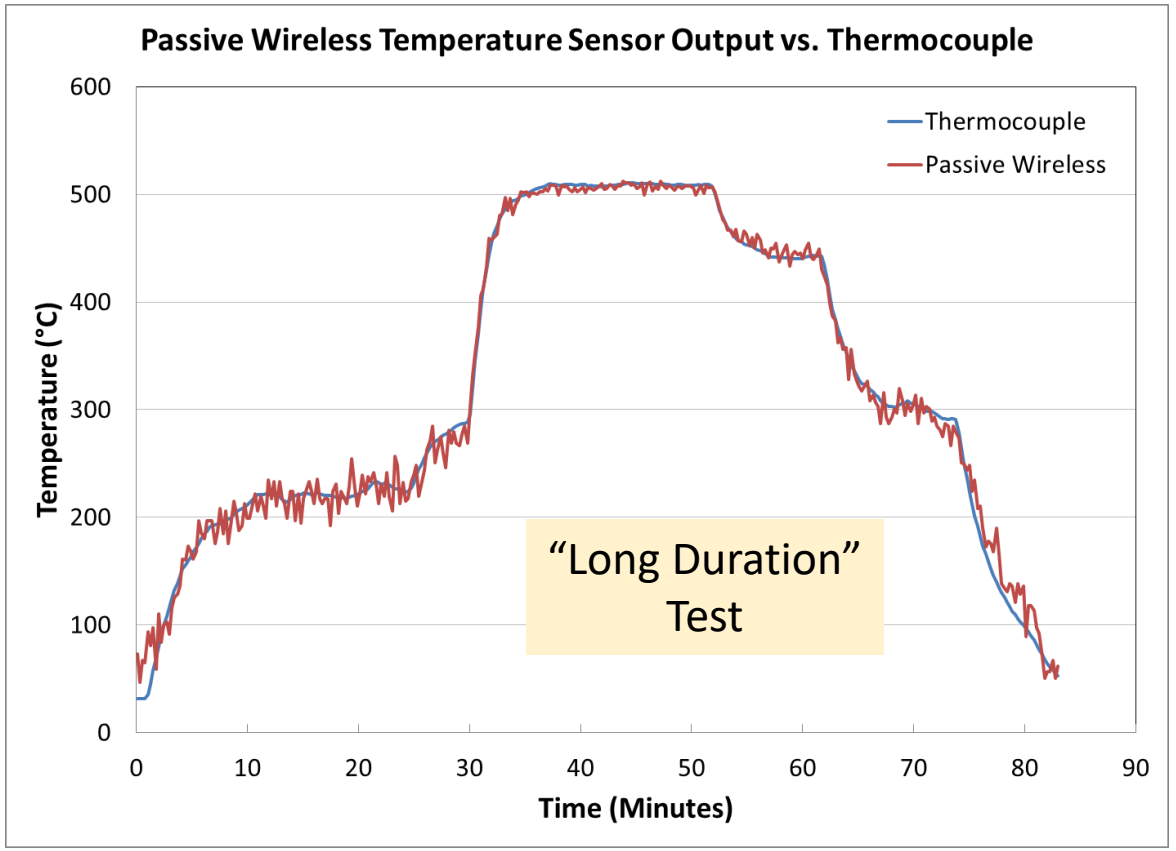
- Calibrated with direct flame heating during rotation



- 2nd Order polynomial fit was determined
- RF interrogation frequency adjusted to 1.48-1.64 MHz, trigger timer modified to 110ms

Passive Wireless Temperature Sensing

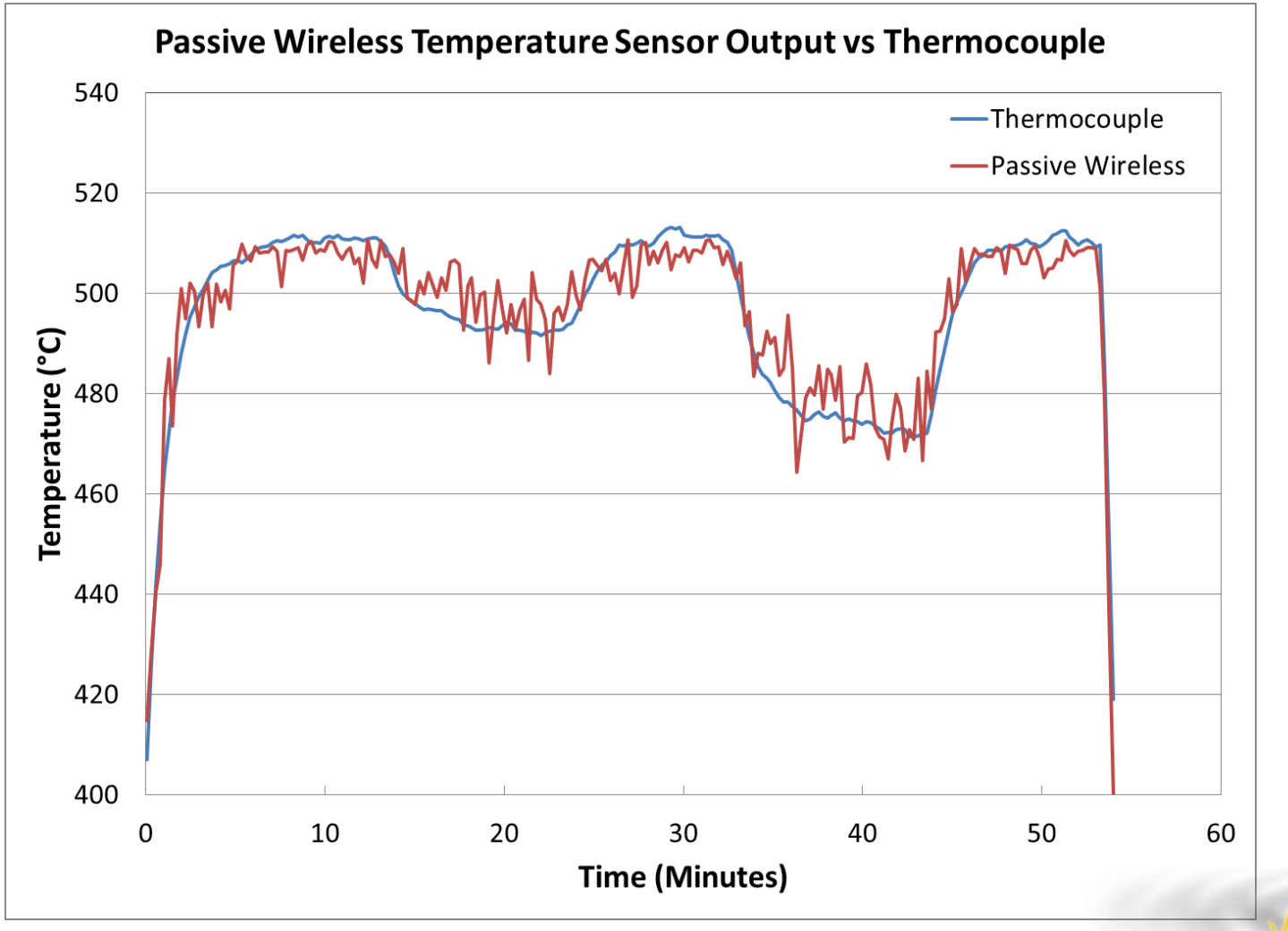




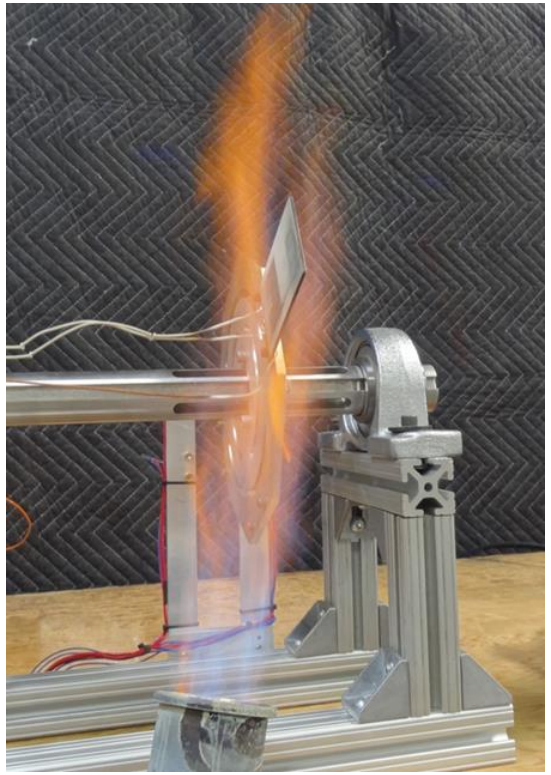
- Good correlation was obtained between passive wireless temperature sensor and attached reference thermocouple reading

High Resolution Test at 500°C

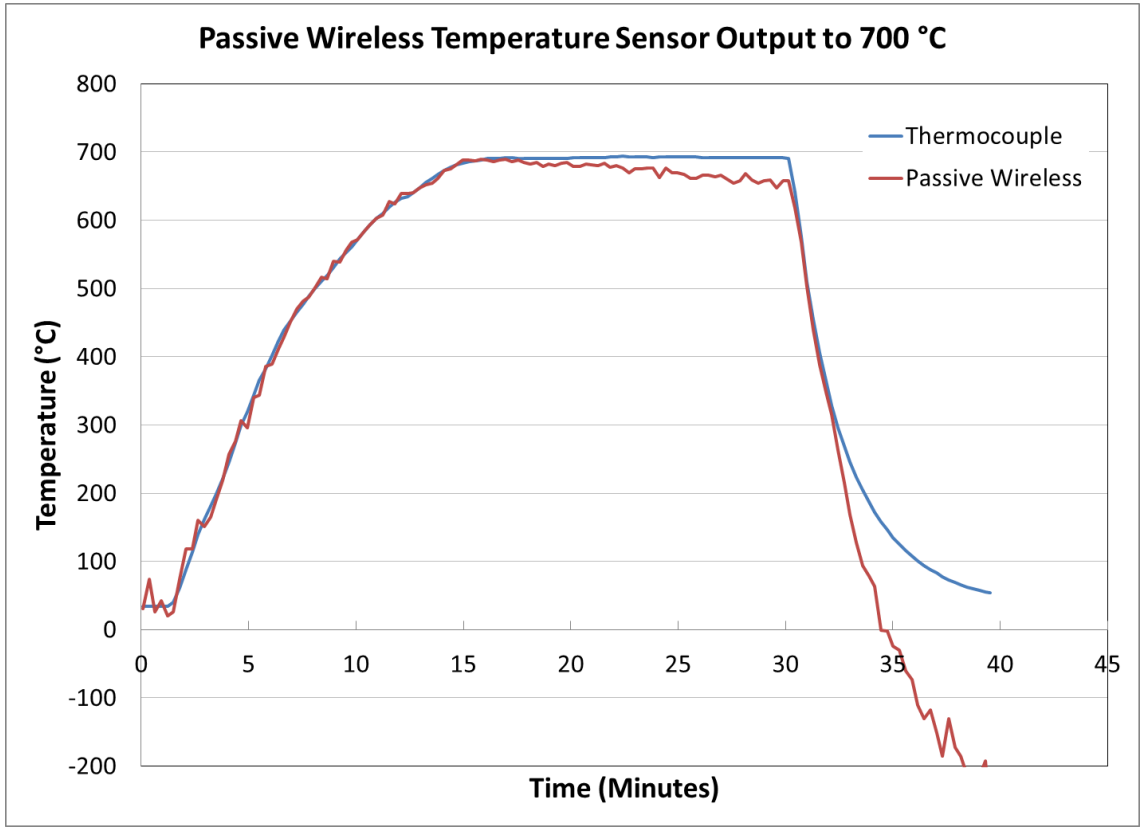
- Performed to precisely monitor small changes in temperature at 500°C
- RF Interrogation frequency tightened to 1.46-1.56 MHz (precludes measurements below 400°C)
- **Good agreement with reference thermocouple to within 10°C**



Passive Wireless Sensing at 700°C



- Sensor output drifts during 15 minute soak at 700C, altering the temperature/frequency relationship for this sensor
- Caused the resonant frequency to jump between 2 different triggered sweeps, pickup coil required repositioning



- Further sensor development is required for passive wireless measurements above 500C

Summary

- MesoPlasma™ printing provides high performance products, currently used in demanding environments including commercial aircraft, satellites, propulsion systems, gas turbine engines, etc.
  - Conformal integration of sensors, heaters, RF traces, & antenna elements
  - Printed instrumentation can survive high temperature, harsh environments
  - **Provides performance and cost advantages compared to conventional approaches**

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