Direct Write of Non-Planar and 3D Sensors & Antenna using Optomec's Aerosol Jet Technology

OPTOMEC®
Production Grade 3D Printers... with a Material Difference

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Agenda

Who is Optomec?

What is Aerosol Jet & how does it work?

How can aerosol jet enable passive wireless devices & Sensors?

Examples of sensors and circuits on 2D & 3D substrates

Summary & Key benefits

Differentiated Leader in Additive Manufacturing

Power
Healthcare
Aviation

illumina

United Technologies

ALCOA

LITEON

BAE SYSTEMS

xerox

Boston Scientific

300+

Optomec Global Installations

50+ Issued
50+ Pending

Optomec IP

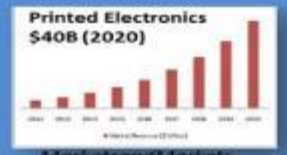
40+

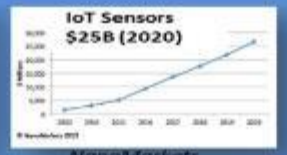
Optomec Material and Automation Partners

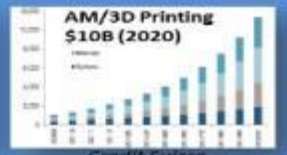
90+

Optomec Employees Albuquerque & St. Paul

Targeting High Growth Markets & Applications







Privately Held – Profitable – Recent Investment from GE

BOEING

Nordson

Rockwell Collins

Johnson & Johnson

BOSCH

LOCKHEED MARTIN

UNITED ENGINE CORPORATION

Optomec Products

Aerosol Jet (AJ)

- Functional materials digital printing (conductors, dielectrics, adhesives, ceramics, etc)
- Printed Feature Size Capability from µm's to mm's
- Key capabilities in printed electronics and sensors

Laser Engineered Net-Shaping (LENS)

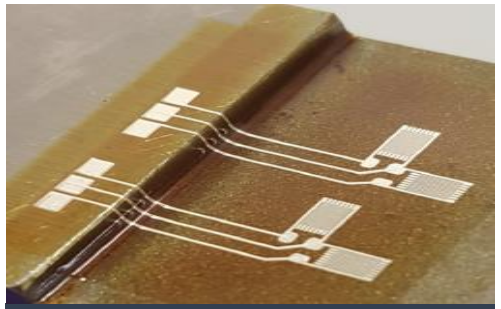
- Structural metals printing (Steel, Titanium, etc)
- Printed Feature Size Capability mm's to meters
- Key capabilities in part Repair, 3D printing, & wear coatings

Aerosol Jet: Technology Overview

- "Input" Low Viscosity nanoparticle and particle free inks
  - Conductors, Insulators, Semiconductors, Biomaterial…
- "Output" ~10µm to mm wide features & thin film coatings down to 100 nm thick
  - High stand off from part (1-5 mm)
  - 2D / 3D Surface Printing
- Cost and Functional Advantages
  - Lower Material and Process Costs
  - Improved End-Product Performance
- Standard System Products
  - Standard Development Platform
  - Medium Volume Production Systems
  - High Volume OEM Print Modules for Integration

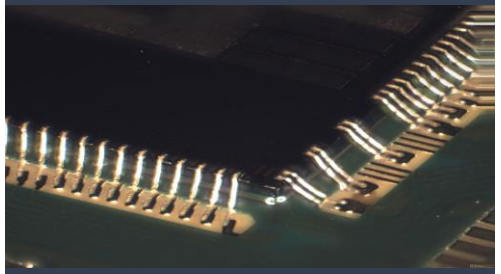
Contactless, Fine Feature Printing Process

Production Ready Platforms



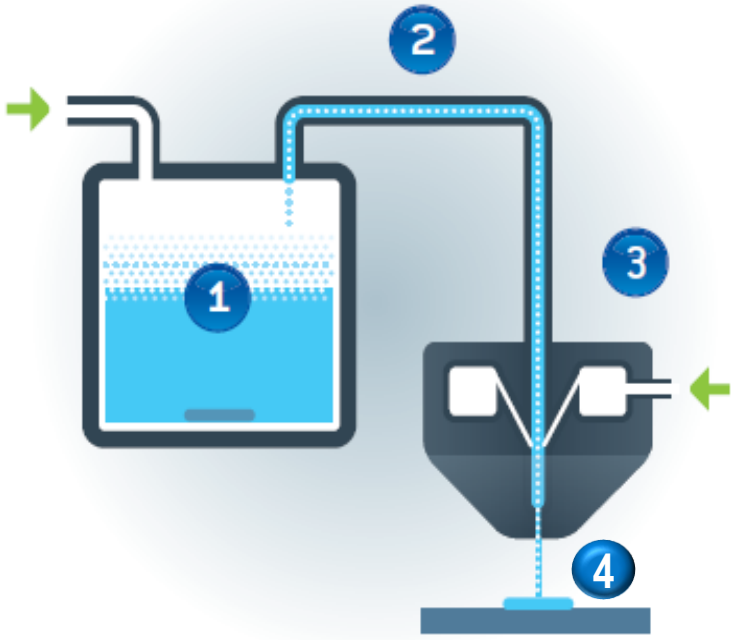
Printed Sensors

Printed 3D Antenna

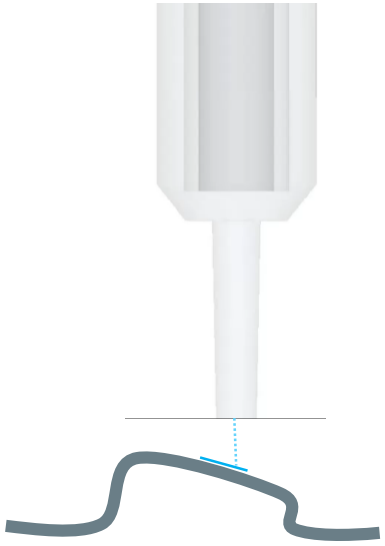


Printed 3D wiring

Aerosol Jet Technology Basics



Planar



Non-Planar

1. Nanoparticle & particle free inks from 1-500cP are atomized into a mist of 2-5 µm droplets
2. Mist is carried from the atomizer to the print head using high purity nitrogen at low flows.
3. Mist enters print head where a sheath of nitrogen collimates & accelerates the mist through a converging nozzle orifice.
4. The mist beam, traveling at >50m/s, impacts both planar & non-planar substrates continuously, enabling a high stand of distance of up to 5 mm. The mist beam can be shuttered quickly to create discrete features.

How Can Aerosol Jet Enable Wireless Passive Circuits & Sensors?

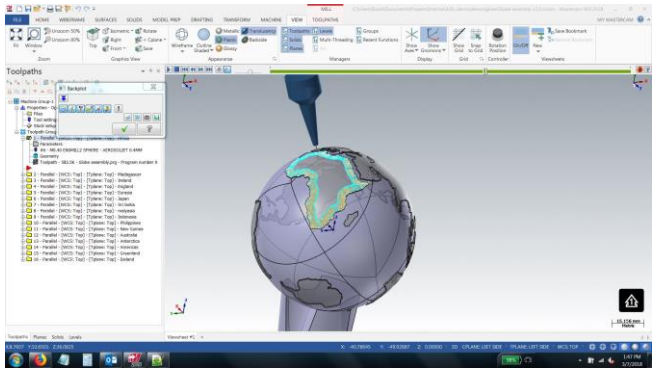
- Digital Printing of functional devices

- Target Applications - Printed antenna, wiring on existing objects or fabricated from scratch, & sensors

- Functional Materials – Conductors, Insulators, resistors, sensing materials & even ceramics

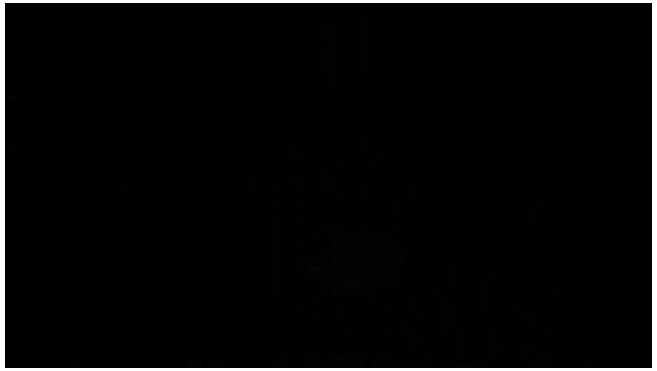
Getting Features on Parts with Aerosol Jet

Design



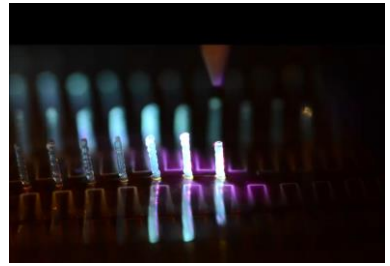
- Start with a DXF(2D) or 3D CAD model
- Convert patterns and geometry to printing paths
- Toolpaths generated with Optomec Software

Print



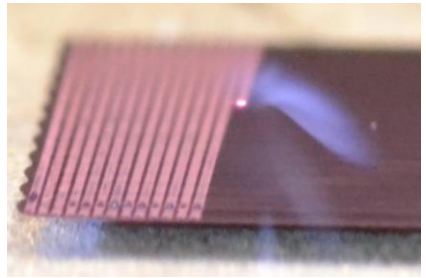
- Place part in machine and align
- Print part!

Post -Process



- UV Cure Polymers

- Laser Sintering of metal inks



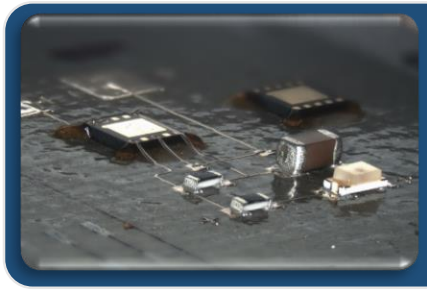
- Oven Sintering & Curing of metals and polymers

What Materials can be printed?

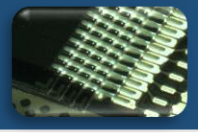
Conductive Metal Inks	Resistive Inks	Polymer/Di-electric Inks
Silver nanoparticle	Carbon particle	Acrylated Urethanes
Silver flake	Ruthenate particle	UV curable Adhesives
Non-Particle Silver	**Common PCB Materials**	UV Curable Acrylics
B-Stage Silver Epoxy	Photo & Etch Resists (ex. SU8)	Polyimide
Copper nanoparticle	Flux	Low DE Polymers
Gold nanoparticle	**Non-Metallic Conductors**	Glass Frit
Platinum nanoparticle	PEDOT:PSS	Silicone
Nickel nanoparticle	Single Walled CNT's	B-Stage Epoxy
Copper-Nickel (Constantan) nanoparticle	Multi-Walled CNT's	Ceramics (Zirconia, Alumina etc)

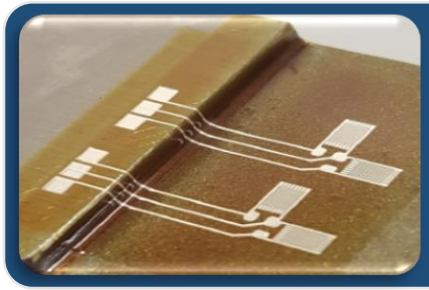
All inks are proven to work with the Aerosol Jet Process & are available from commercial ink vendors.

Target Applications

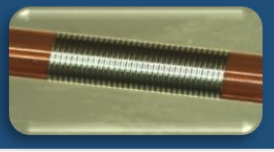


Advanced 3D Packaging & Assembly

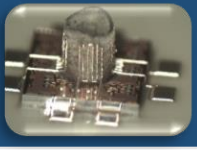
3D Interconnect 
Multi-Layer 
Bonding 
Via Fill 
Shielding 
Attach 



Printed Sensors

Strain Gauge 
Thermocouple 
Gas Sensor 
RF Sensor 
Glucose Sensor 

Printed Antenna

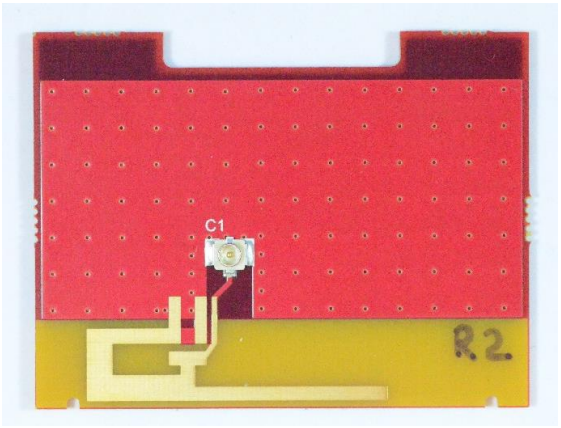
Broadband 
NFC 
Bluetooth 
WiFi 
on Chip 
w/3D Post 

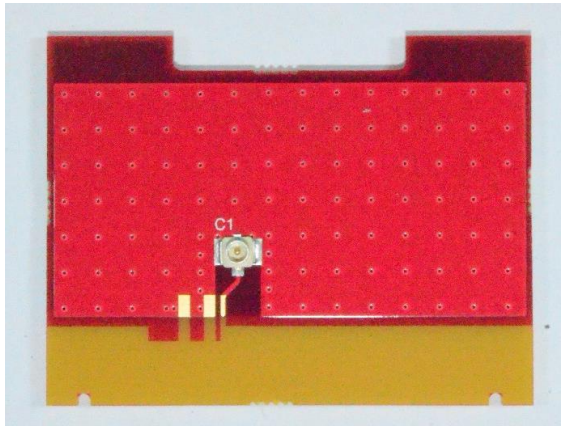
Printed Silver Antenna for 2D and 3D substrates

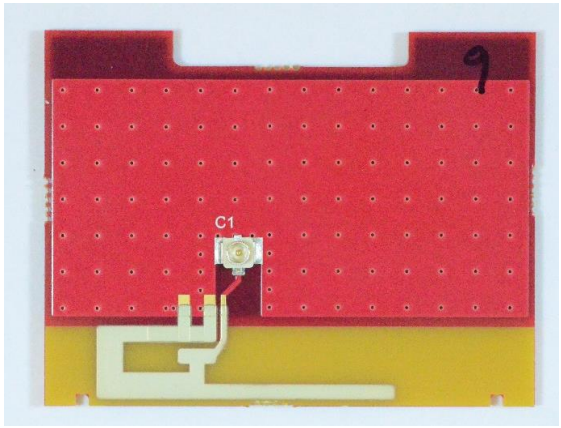
- Embed antenna directly on substrates
- Demonstrated resistivity of 3.59 x 10^{-8} Ω*m after only 1 hour @ 120°C (that is 4x bulk silver)
- Antennas survive:
  - 80/80 Humidity testing
  - 48 hour salt spray (5% solution) with POST peel tape test, 5B adhesion
  - Proven RF performance at 2.4 and 5 GHz frequency
- Decreased material cost and substrate flexibility

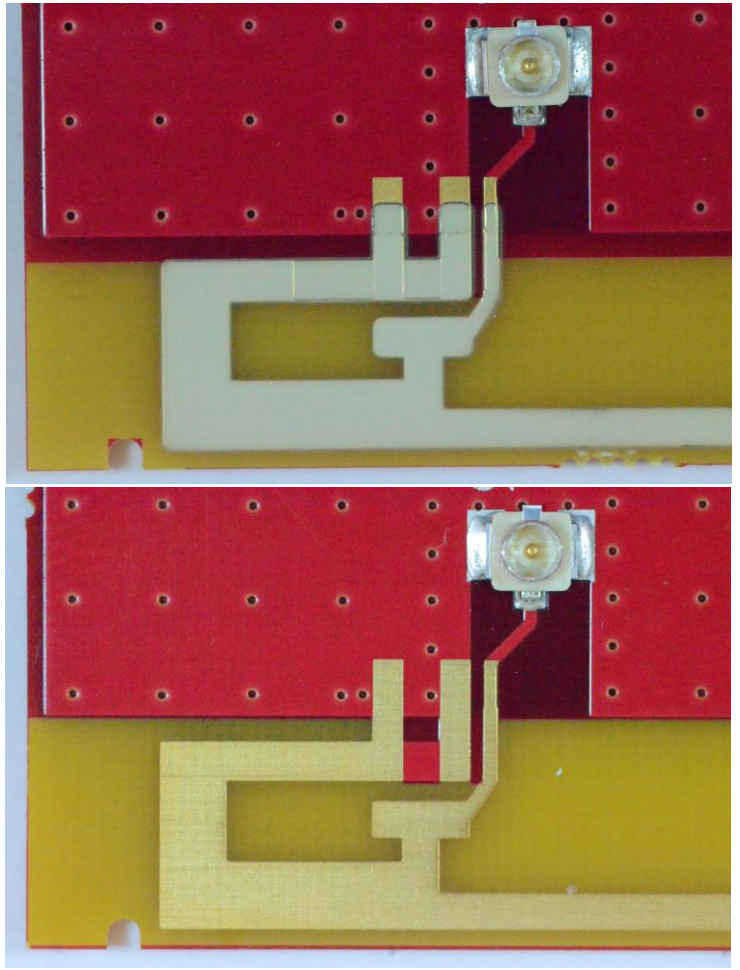
2D Antenna Testing –
Comparing an Apple to a printed Apple

- A reference antenna (left) was created with a standard ½ Oz. copper PCB process
- An antenna blank board (center) which consisted of the ground plane, connector and 50 ohm trace up to edge of the ground plane was created with a standard ½ oz. copper PCB process.
- A printed antenna (right) was printed utilizing the antenna blank

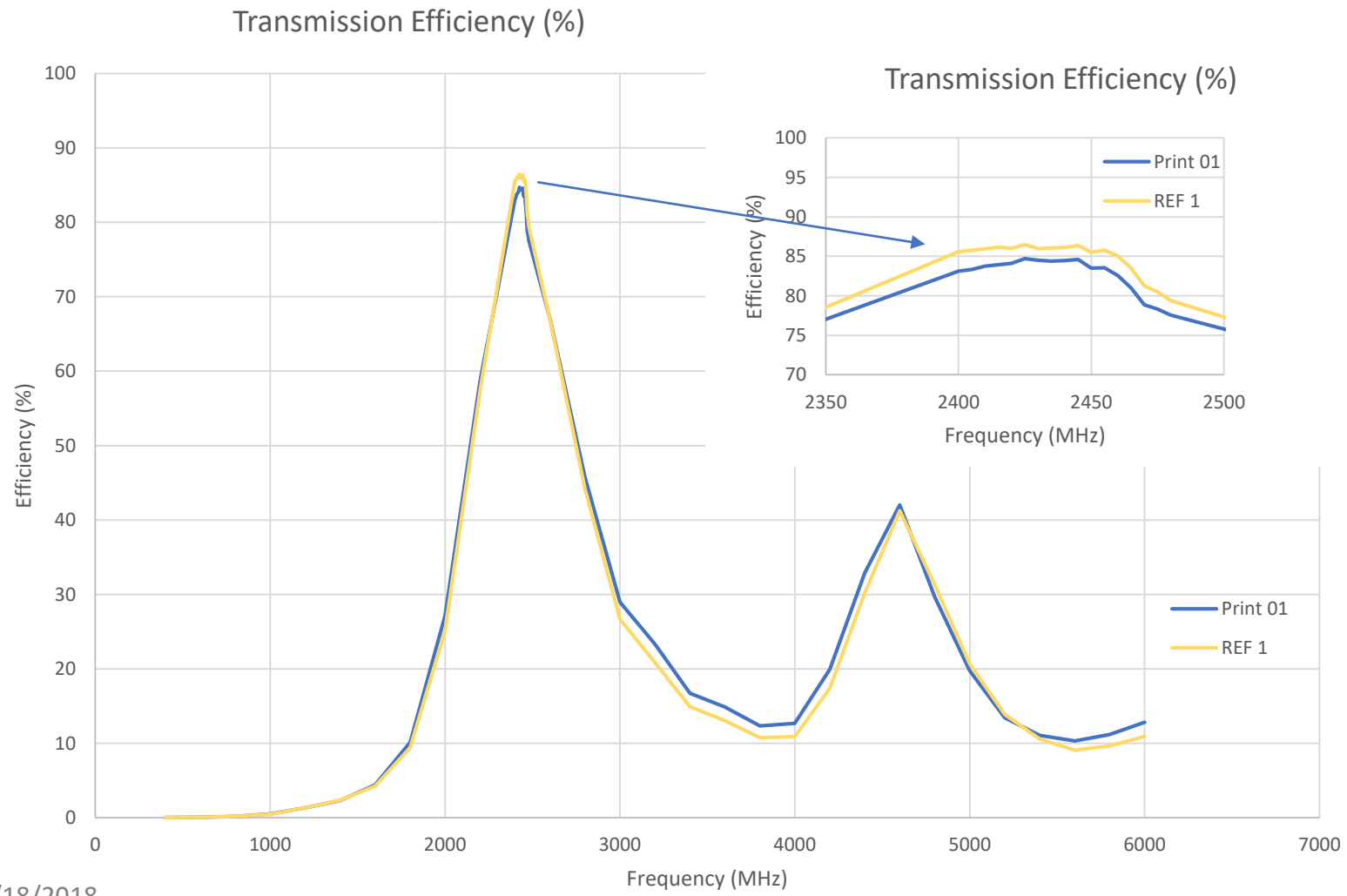




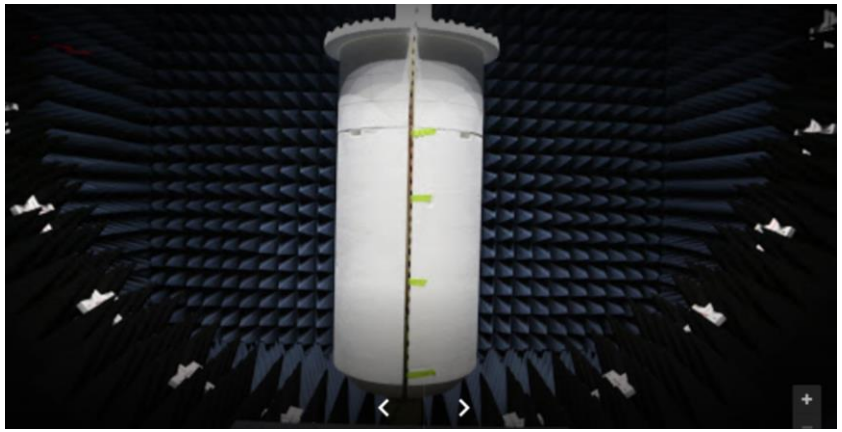




2D Antenna Transmission Efficiency

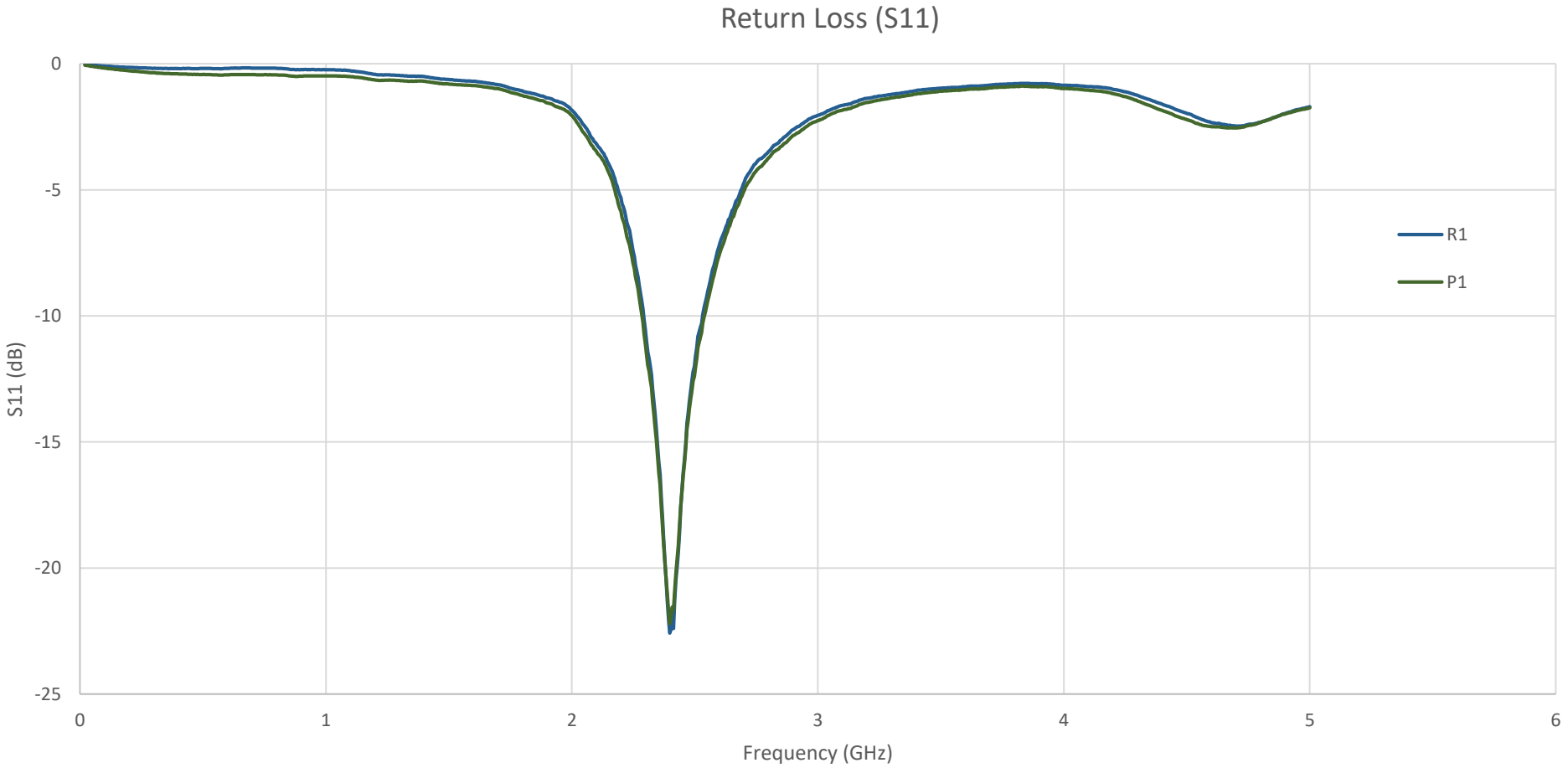


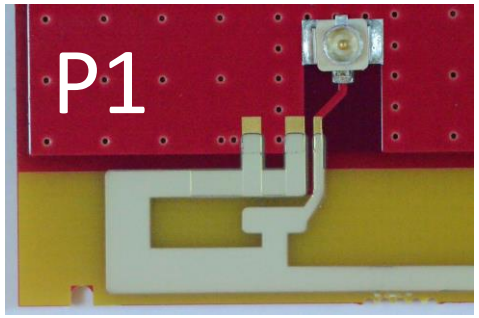
The reference antenna is “REF 1” and the printed antenna is “Print 01”

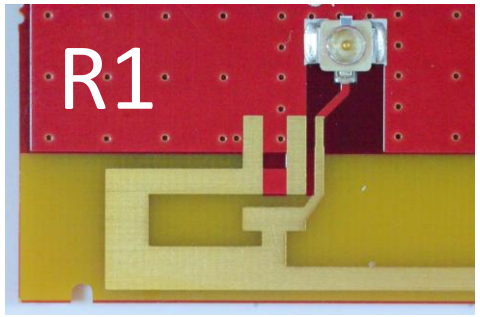


Anechoic test chamber used to complete testing
Courtesy of Northwest EMC

2D Antenna Return Loss (S11)

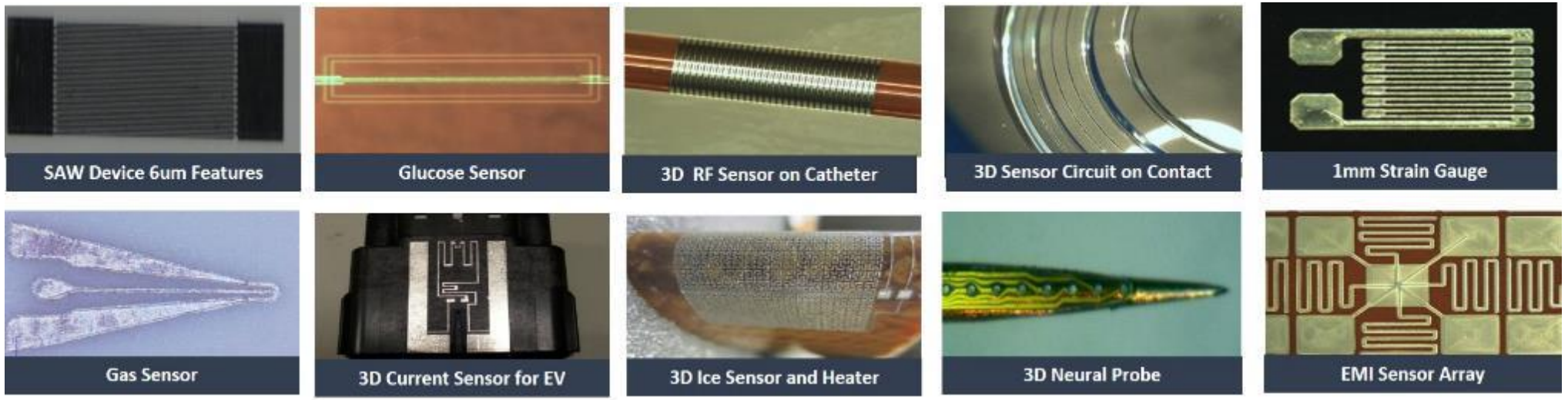






Printing Sensors On 3D Objects with AJ

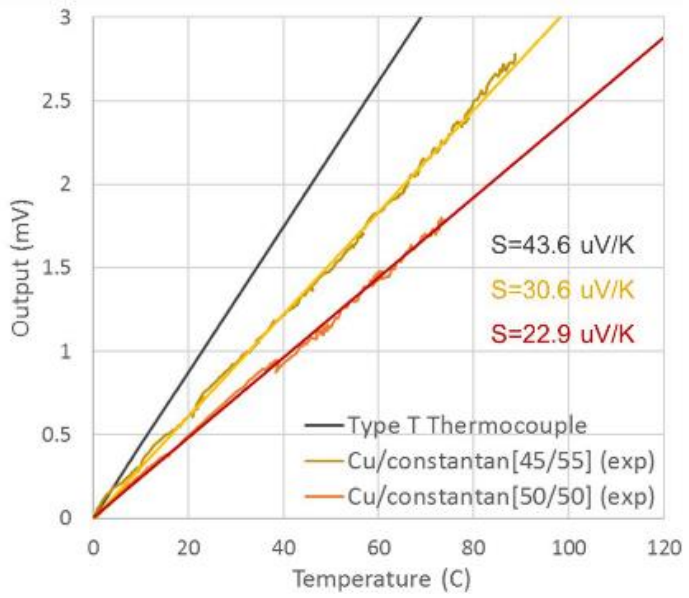
- Print a wide variety of sensor geometries & sensor materials
- Printed directly on to complex non-planar and/or 3D objects, less restrictive than traditional sensors
- Scale sensor size and change geometry to suit application demands

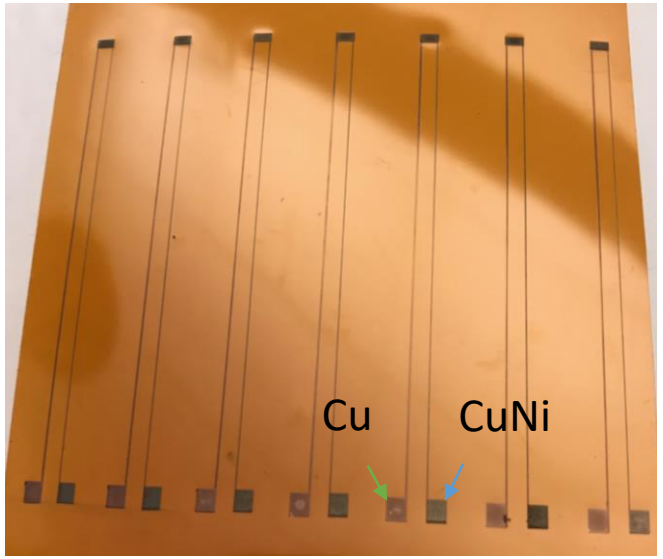


Printed Type-T Thermocouples for Monitoring of Critical Car Engine Components

Printed nanoparticle based Copper – Constantan junction

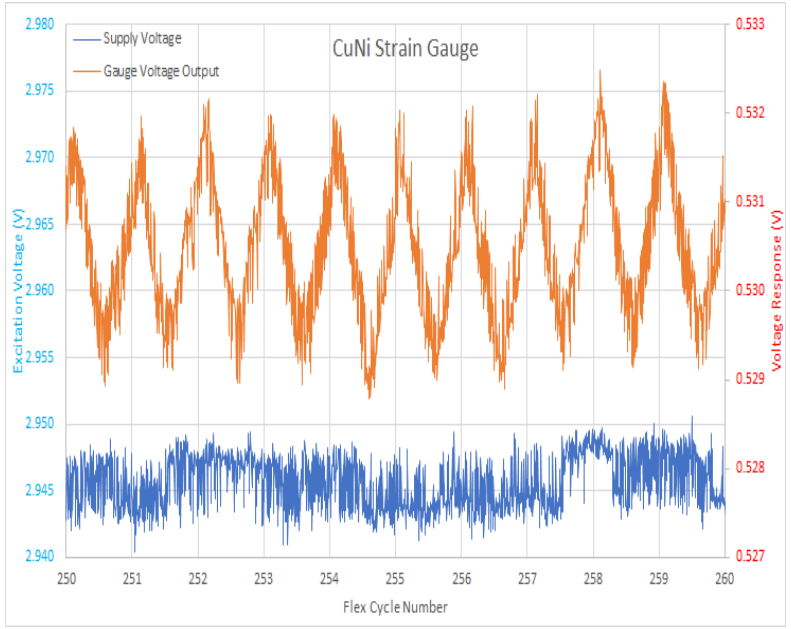
- Seebeck coefficient approaches that of T-type thermocouple
- Predictable, Linear Sensor performance
- Calibrated to provide accurate response



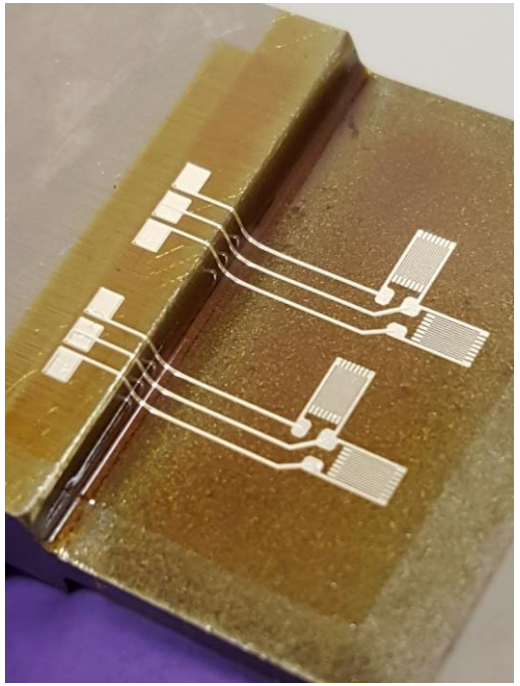


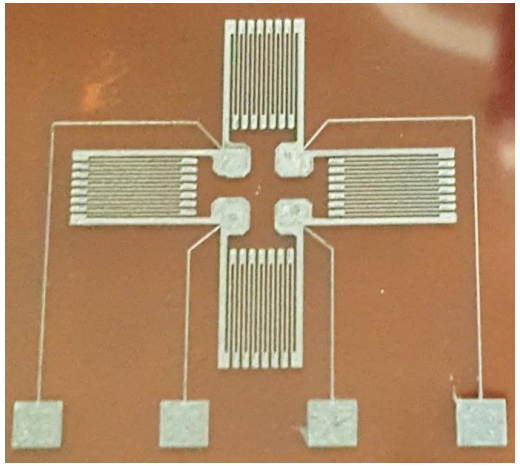
Printed Constantan Strain Gages

- Repeatable strain gages printed with Copper-Nickel Alloys (Constantan), foil gage materials
- Proven performance on Kapton substrates, similar to traditional foil gage
- Geometry and print thickness can be customized to produce specific resistance



- 1.3-3V Excitation voltage
- High gage Factor (>2)
- Full bridge printed
- Cyclic bending over 60 mm diameter pipe
- >5,000 flexes without signal degradation

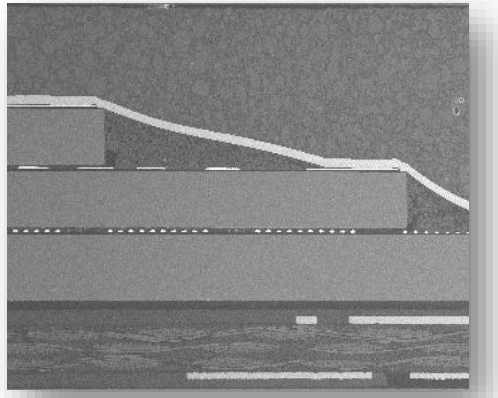


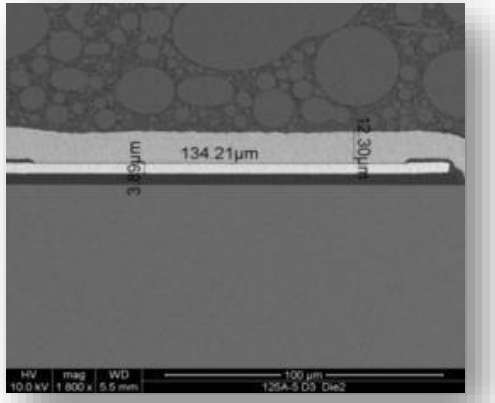


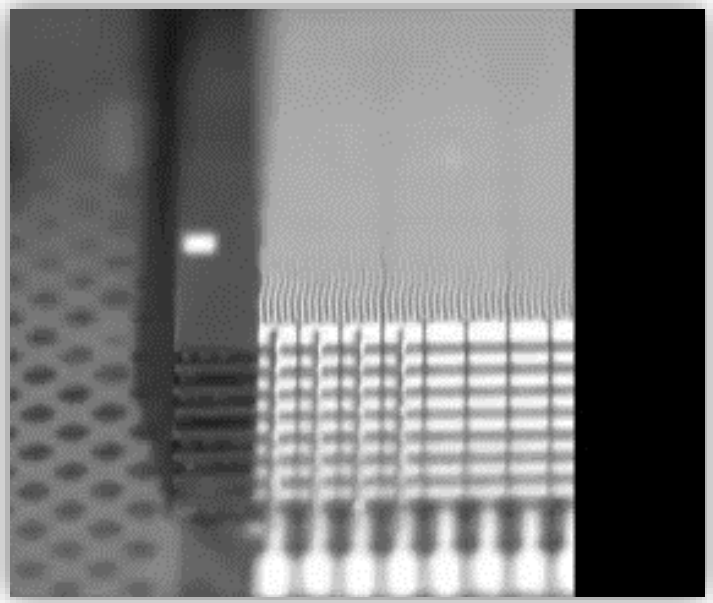
3D Interconnect Printing

Multi-Die Stacks

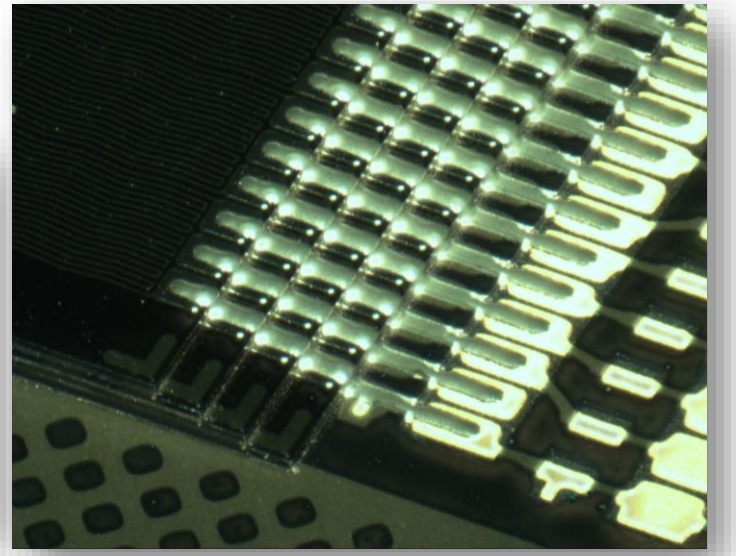
- 150 μm nozzle – Producing ~ 30μm wide traces x ~7 μm tall
- Package heights of <4mm require no Z-axis (typical package height <1mm)
- Printing speed shown is 5 mm/s; roughly 1 line/second includes 2 passes equivalent to 8 wire bonds.
- Printing silver for interconnects; UV acrylic for fillets
- No challenges scaling to higher die stacks, just print a longer line.







8 Die Stack



4 Die Stack

3D Interconnect Printing

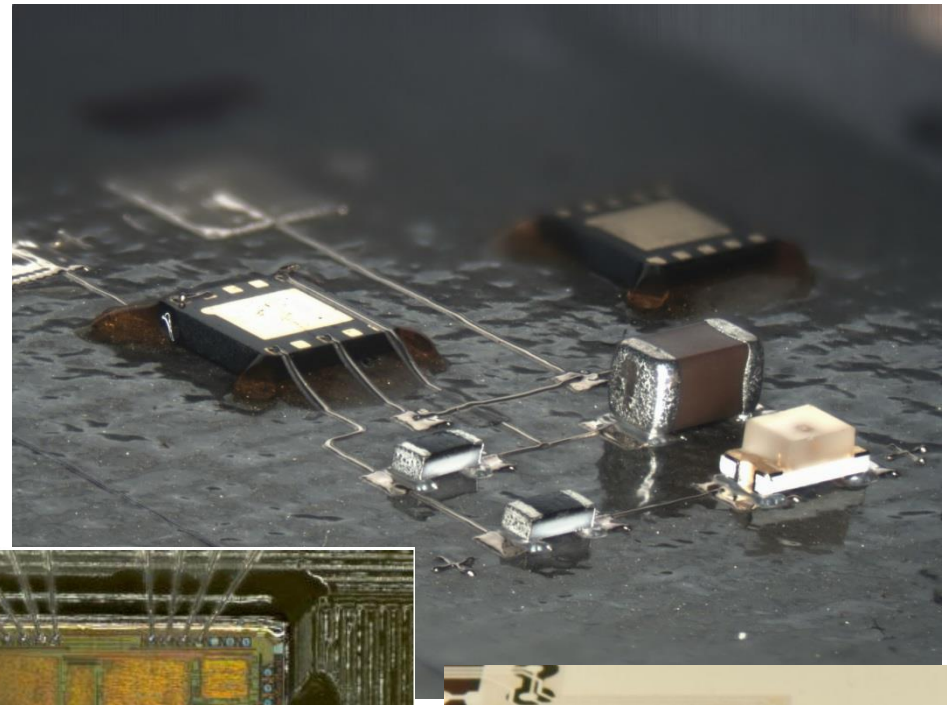
Single Bare & Packaged Die

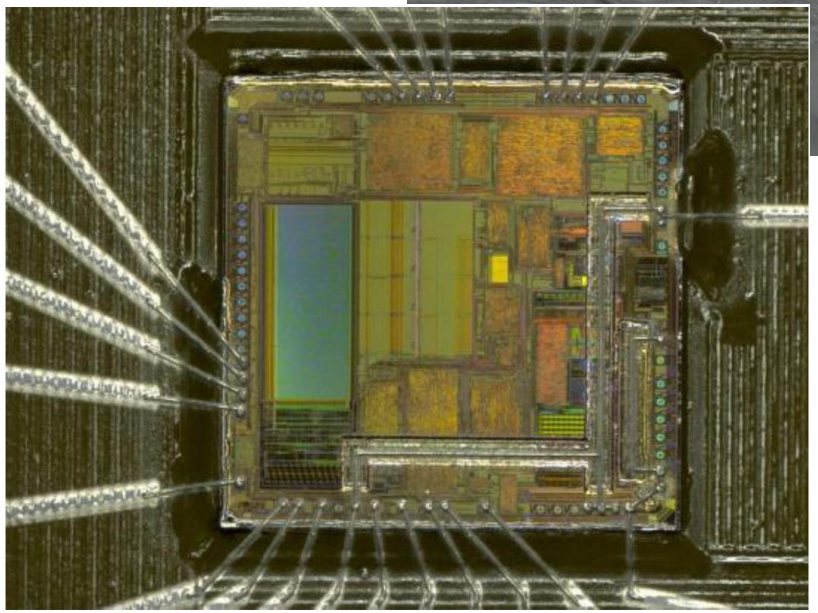
All prints shown performed with 2-axis motion without any tilting (for 30-45° Fillet)

Interconnects down to <20 microns have been demonstrated at <50 micron spacing

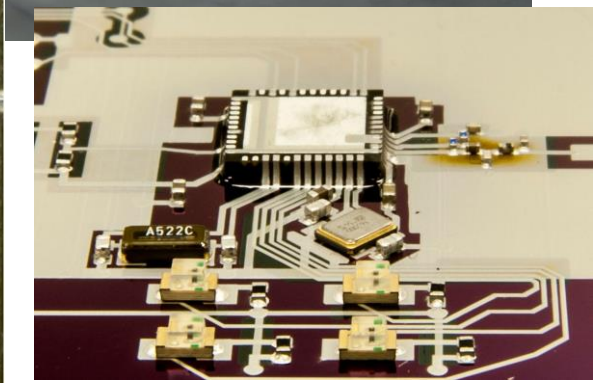
Lower inductance than wire bonds, decrease chances of coupling/cross talk

Enable unique die configurations for thermal performance OR RF performance





Courtesy of LPS

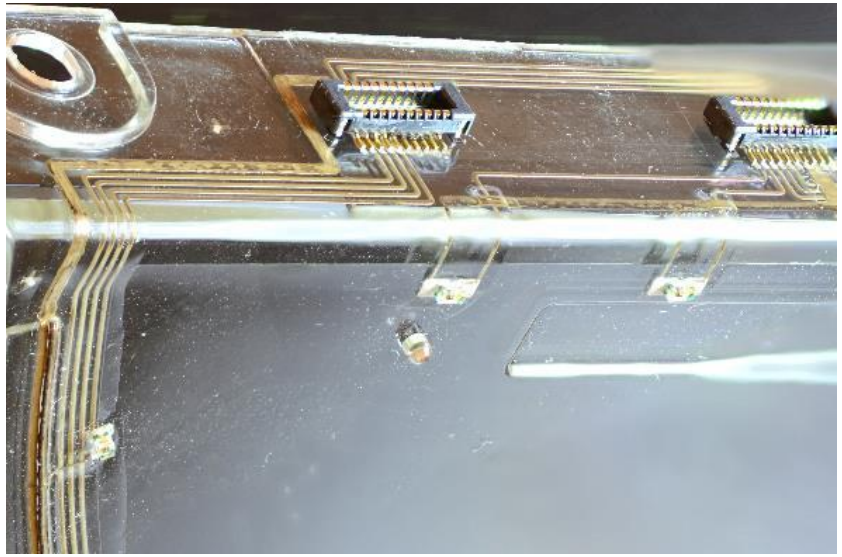


Courtesy of Draper Labs

Printing of Multi-Layered Circuits

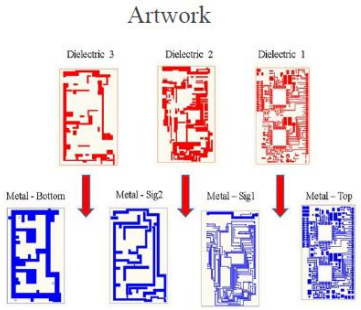
- Print alternating layers of conductor & dielectric
- Conductor materials are thermally sintered
- Di-electric materials are UV cured on-the-fly allowing for multi-layered circuits and bridges
- Passives can be printed as well

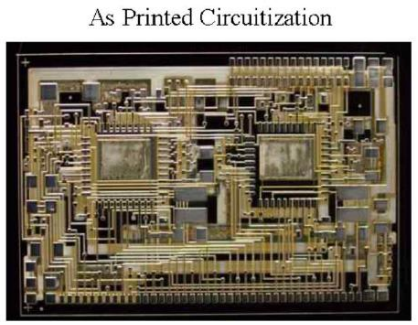
Printed Circuits on a Wearable Device

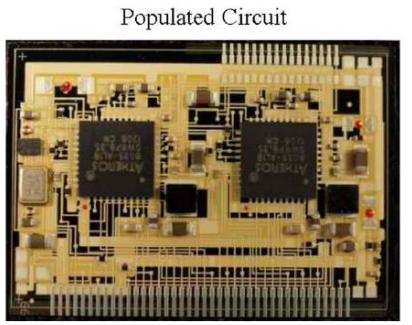


2D 7 layered 5A power supply circuit

Art to Part!







Courtesy of LPS

Summary & Key Benefits

Optomec is an additive manufacturing leader creating innovative material deposition technology

Optomec's Aerosol Jet printed electronics are enabling for prototyping and production of:

- Conformal printed circuitry
- Conformal printed sensors
- Non-planar 2D & 3D IC interconnect methods

Optomec is continually developing materials and methods to deliver solutions in these areas

Benefits of Conformal Printed Circuitry with Aerosol Jet:

- Enable new design configurations
- Fully additive, digital process
- Overcome limitations of existing 2D circuitry methods
- Print wide variety of materials onto a large set of substrates
- Embed circuitry directly on substrates without geometrical limitations
- Create high performance circuits and sensors for real world applications

Questions?