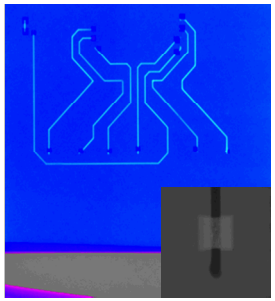
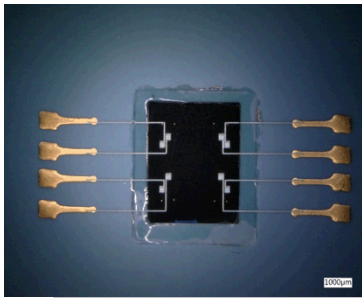
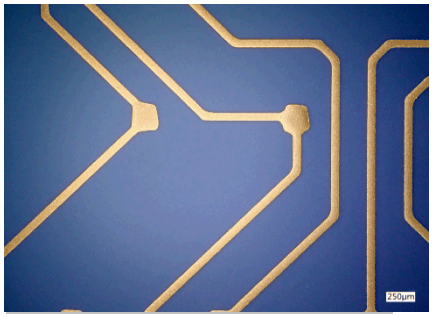
Additive Manufacturing and Digital Printing of Emerging Materials

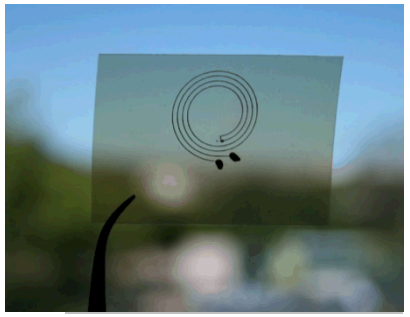
Adam Cook, Chris DiAntonio, Tim Boyle, Nelson Bell, David Keicher,William Reinholtz, Tom Chavez

SAND2017-0929PE









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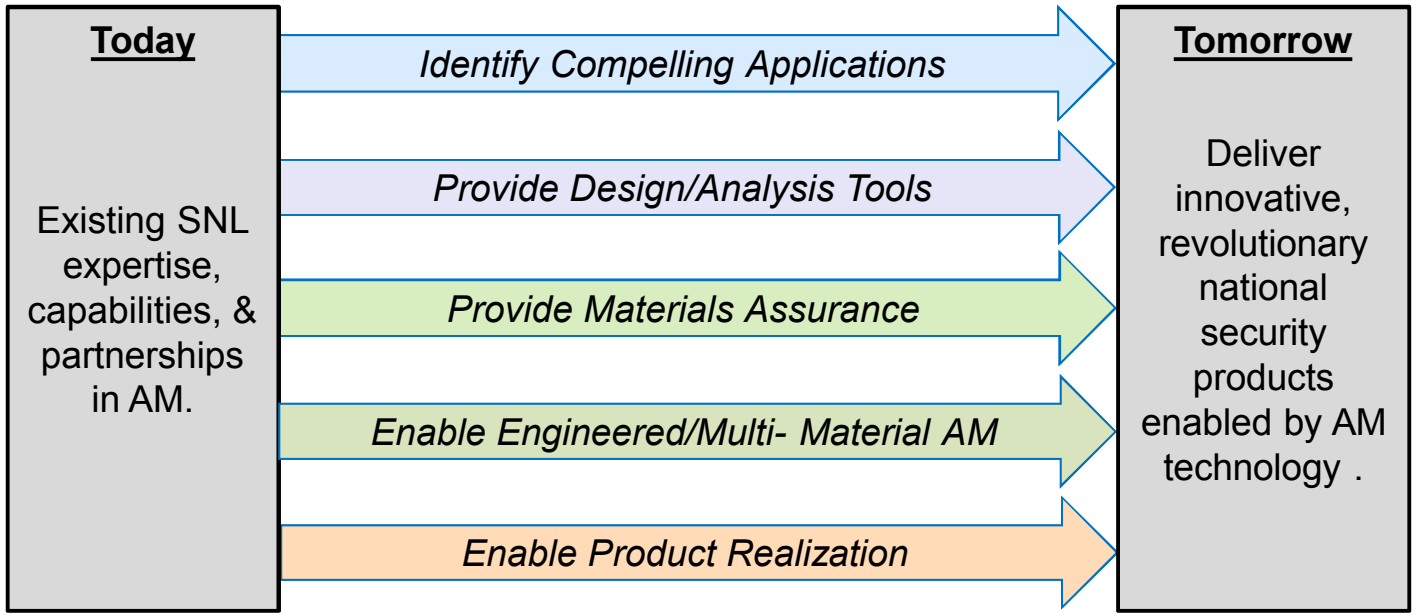
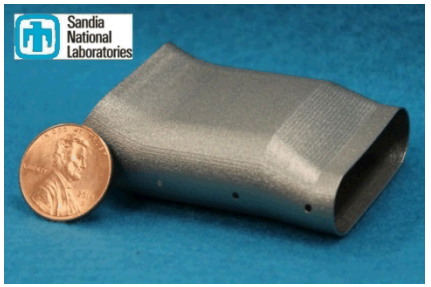
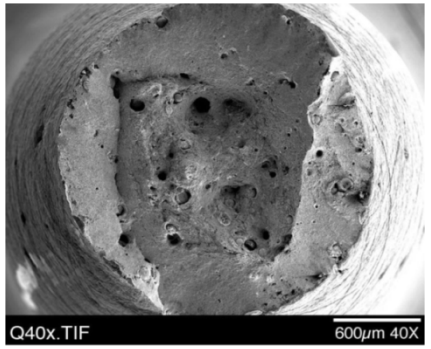
Sandia's additive strategy

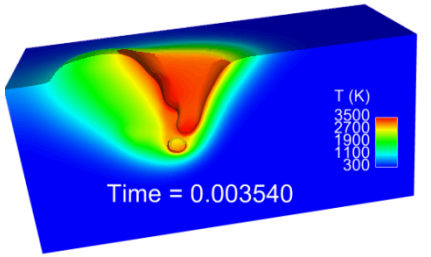
Vision: *We will deliver innovative national security products – impossible to create with traditional technologies – by exploiting the revolutionary potential of Additive Manufacturing.*



5 Strategic Thrust Areas







Additive manufacturing technologies support rapid component realization

Sandia National Laboratories

MakerBot

stratasys

sonoplot

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

3DSYSTEMS

CAD TO METAL
Arcam AB

nScrypt

Nordson
EFD

eos

VOXEL8

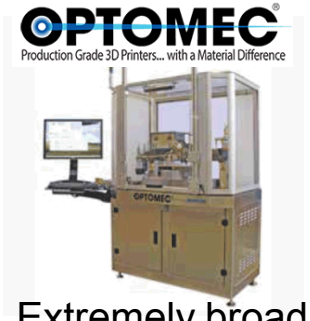
Direct write explained

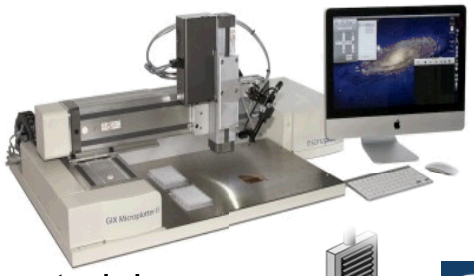
A suite of layerwise additive manufacturing techniques for deposition of enabling materials

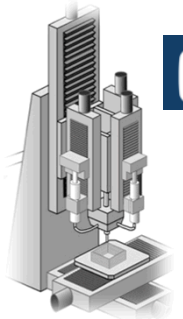
sonoplot

nScrypt

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







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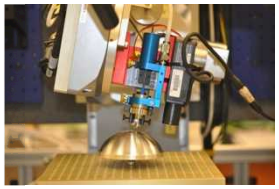


Nordson EFD

- Extremely broad materials compatibility (1-1,500,000 cP)
- Supports 3D printing and conformal depositing to 1 micron
- Readily supports component fabrication via deposition of enabling materials and integration of ASICs

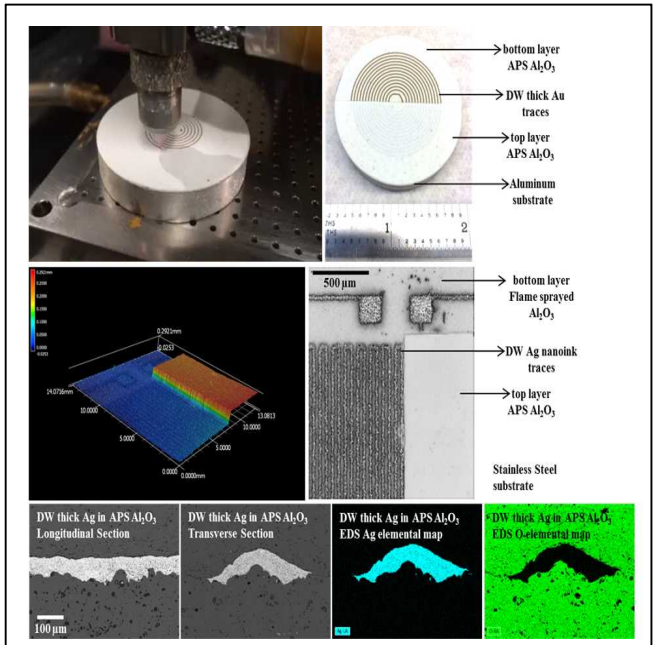
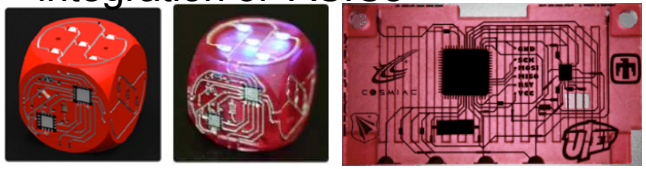
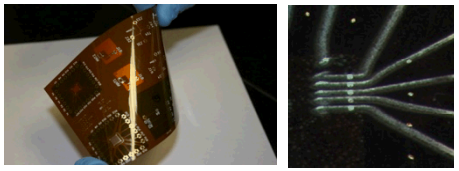


Figure 6: DW EC thick Au paste spiral, Ag nanoink traces, and thick Ag paste traces embedded between thermal sprayed Al_2O_3 underlayer and overlayer.

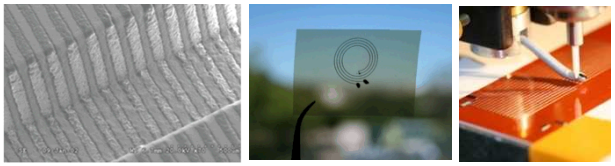
Additive Manufacturing of Hybrid Circuits
Pylin Sarobol, Adam Cook, Paul G. Clem, David Keicher, Deidre Hirschfeld, Aaron C. Hall, and Nelson S. Bell Annual Review of Materials Research, Volume 46



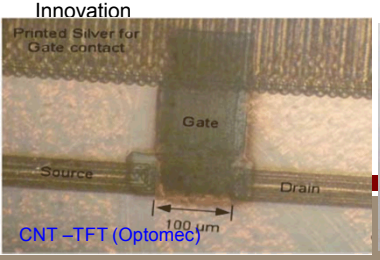
ASIC integration using DW metallization, W.M. Keck Center for 3D Innovation



Printed wire bond replacement at die level interface

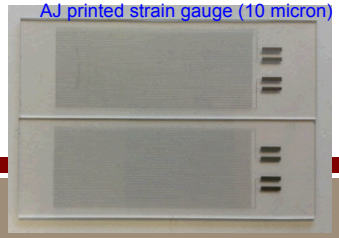


Nanoparticle ink printing on non-planar and thermally sensitive substrates

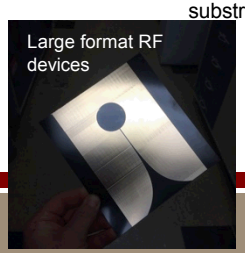


CNT –TFT (Optomec)

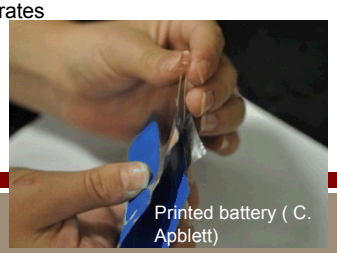
Printed ferrites (C. DiAntonio, A. Cook)



AJ printed strain gauge (10 micron)



Large format RF devices



Printed battery (C. Apblett)

Component Integration Concept

Direct write technologies enable access to materials not supported by conventional printing processes

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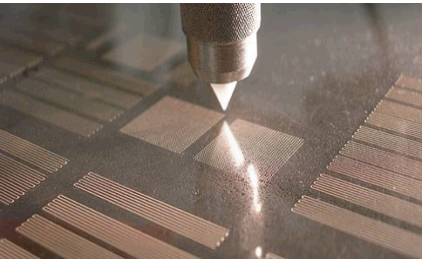
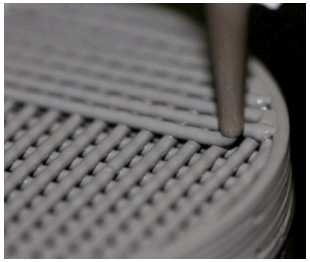
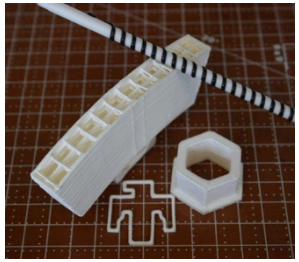
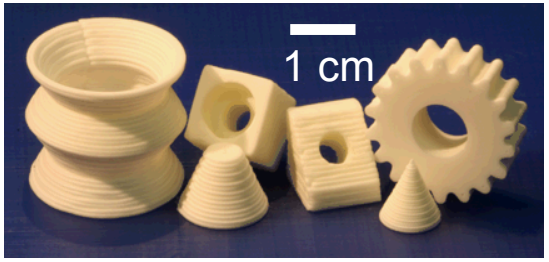
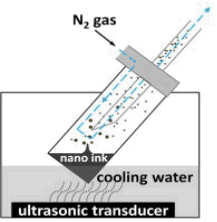
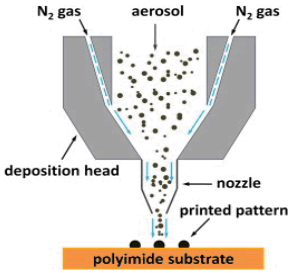
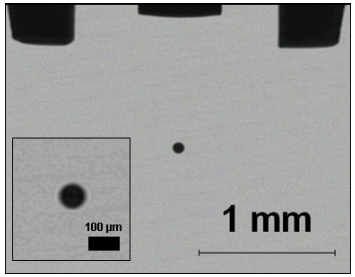
Direct Write by Extrusion Casting

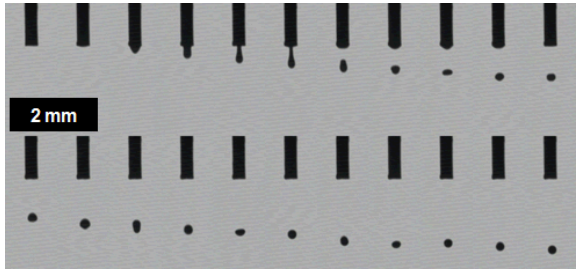





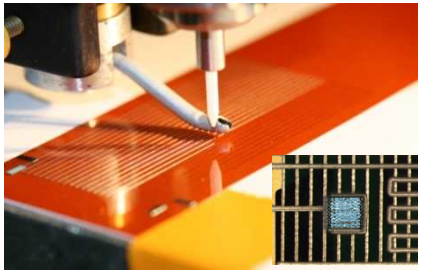
Direct Write by Aerosol & Ink Jet Deposition



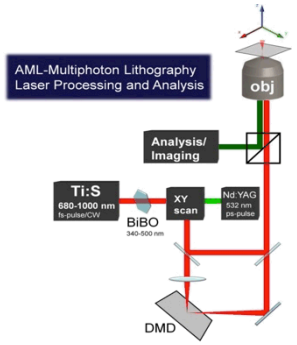


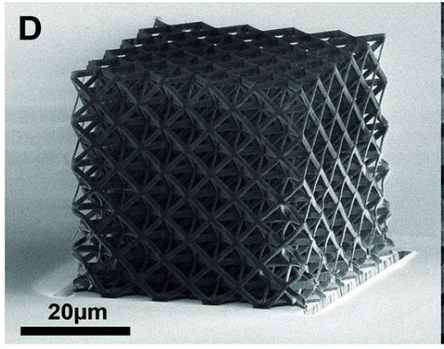


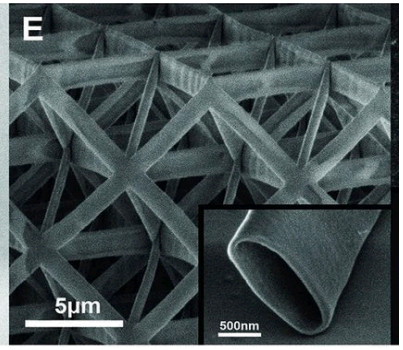


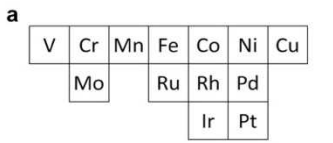


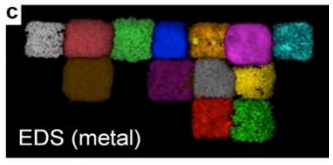
Direct Write by Laser Lithography

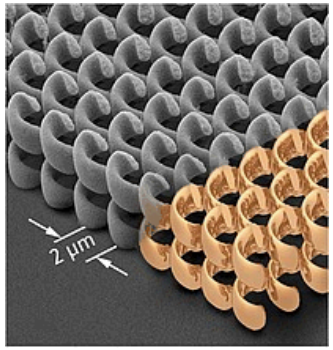






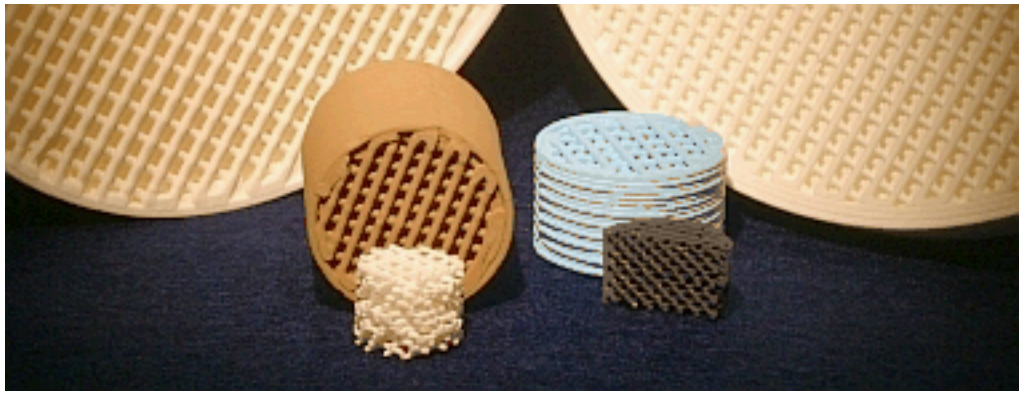


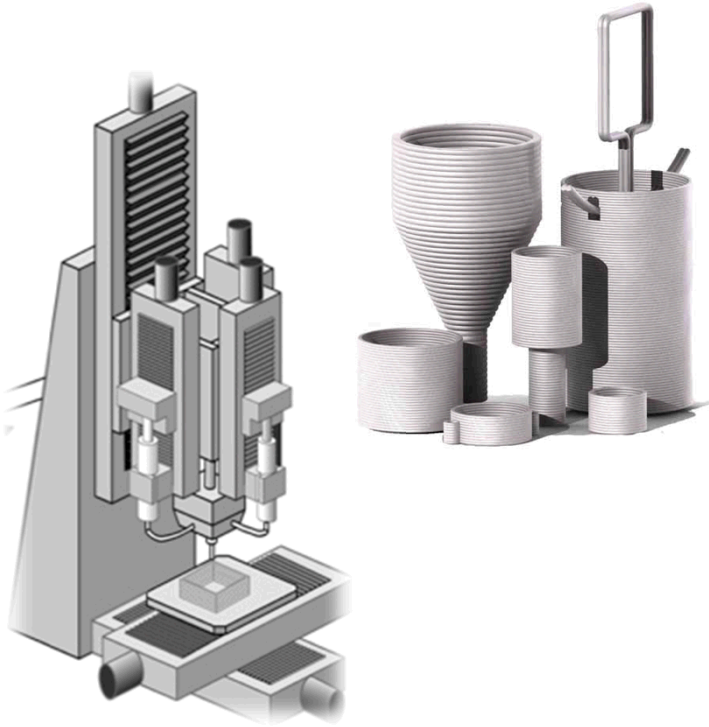


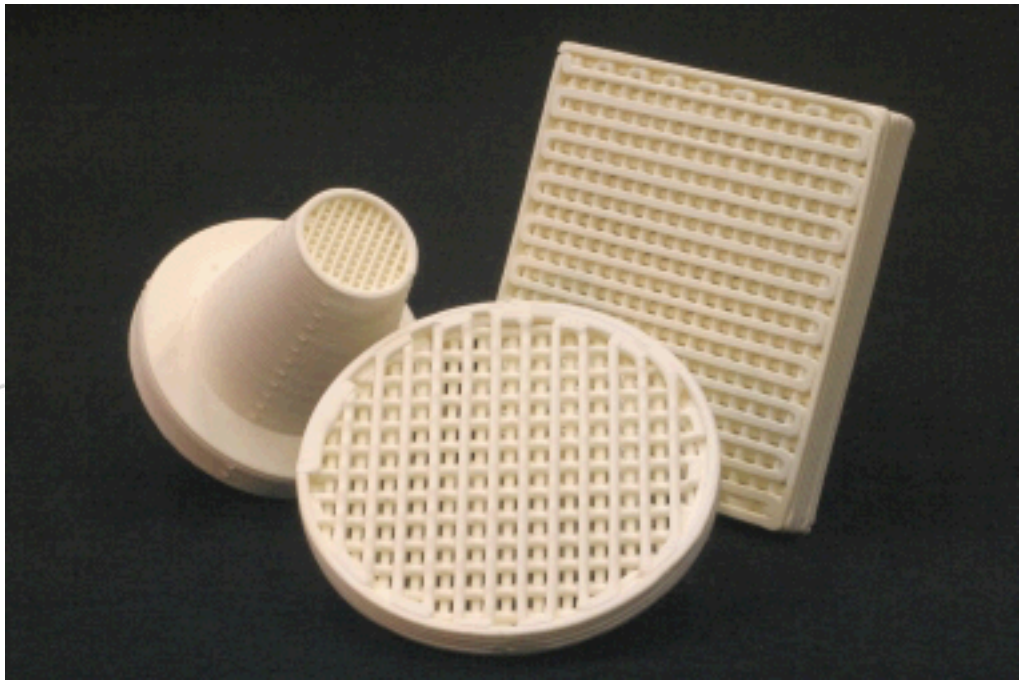


Ceramic Direct Write Technology (Robocasting) was Invented and commercialized by Sandia

- Robocasting Enterprises now commercially manufactures catalyst supports, filtration membranes, and labware using ceramic slurry processing



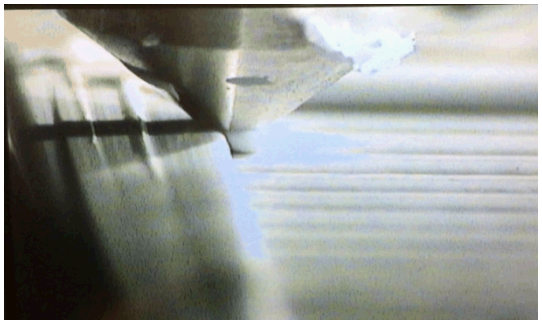


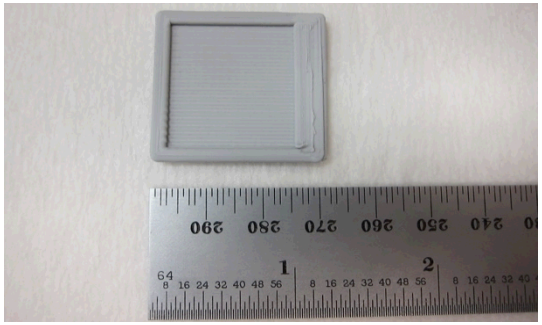


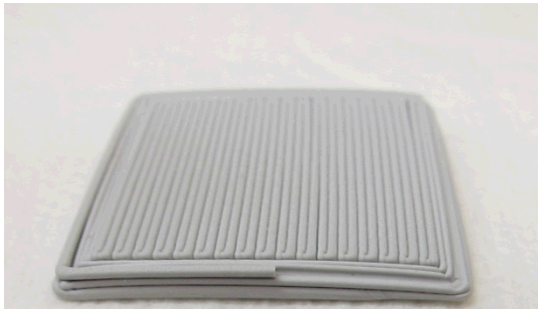
Images courtesy of Robocasting Enterprises, LLC

Sandia is currently engaged in advancing ceramic additive manufacturing through composite processing

Materials and process improvements have resulted in net shape printing of monolithic coupons with considerable green strength



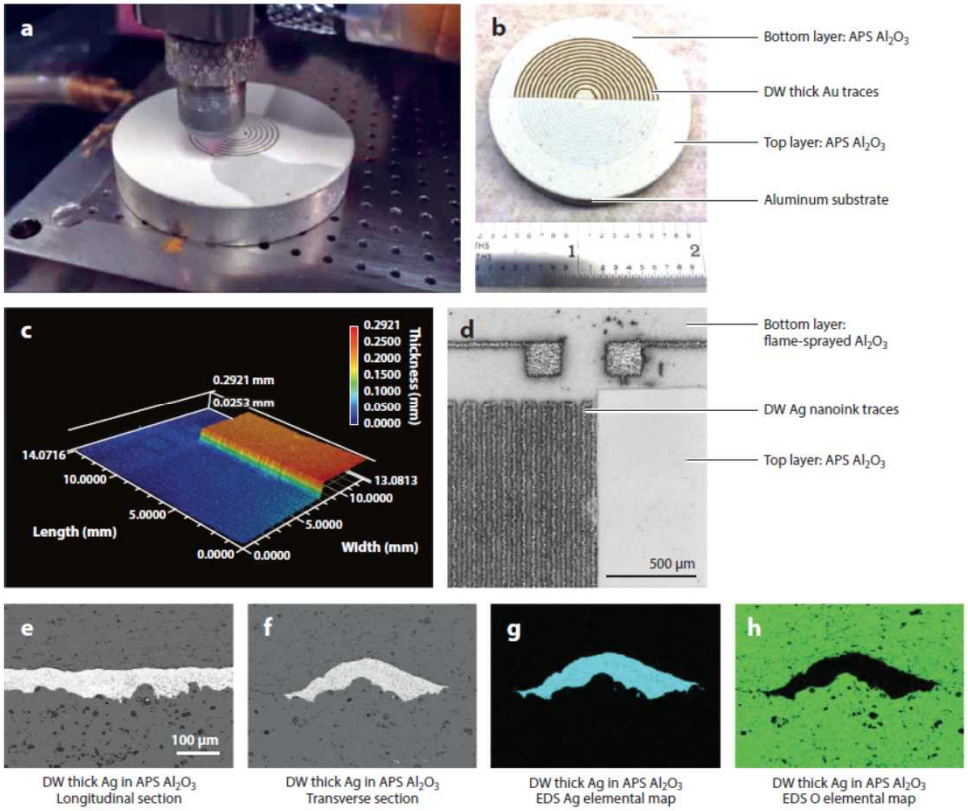


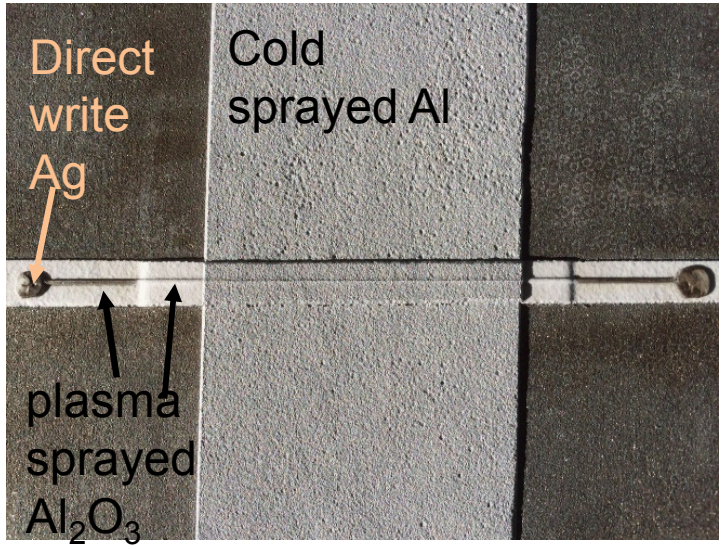


Direct write printed polymer-alumina specimens in the green state.

Integration of thermal spray and direct write processes

towards coils and embedded sensors





Strain Sensor? Resistivity changed with processes

10Ω after binder burn off

1Ω after plasma sprayed Al_2O_3

→heat + more densification

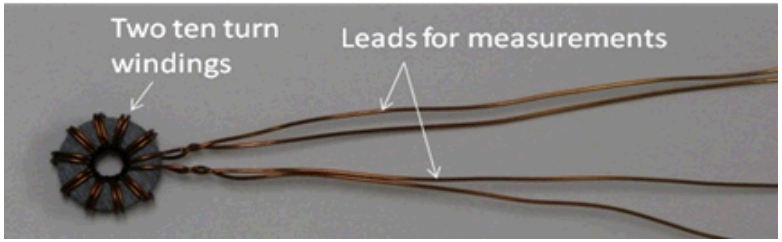
2Ω after cold spraying Al

→ strained

- First step toward additive manufacture of high-temperature capable coils for electromagnetic applications.
- Succeeded with preliminary demonstration of direct write Ag conductors embedded in plasma-sprayed alumina and subsequent cold sprayed coating.

Direct write LTCC for transformers

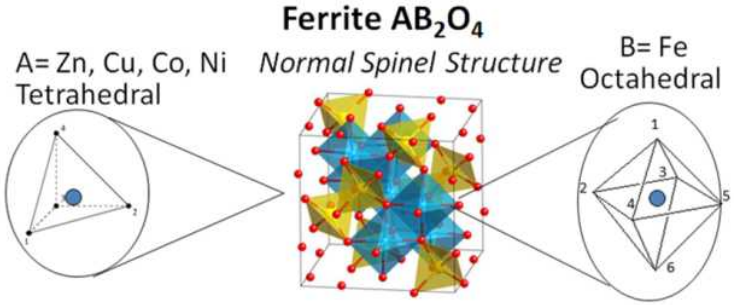
Single greatest technology gap limiting further enhancements of monolithic transformers lies with the material system



- Development of novel LTCC ferrite material(s) with significantly improved magnetic performance
- Explore novel designs that reduce leakage inductance (e.g., use of leakage shorting coils) and marry them with the new ferrite –
- Reliably operate at high voltage – increase the output voltage of the transformer
- Decreased core loss and a higher resistivity
- Size and cost reduction relative to existing state of the art LTCC transformers
- Reduce leakage inductance to allow higher output voltages by preventing MOSFET breakdown
- The enhanced material supports multiple initiatives including initiators and fuzing

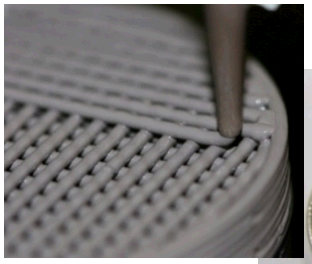
Approach

- Novel synthesis – Composition, processing, controlled dopants
- Characterize thermal sintering/densification behavior, microstructure
- Establish synthesis-composition-processing-microstructure-properties link
- Identify new design concepts that enhance flux coupling



NZCF: $Ni_WZn_XCu_YFe_ZO_{(W+X+Y+3Z)}$

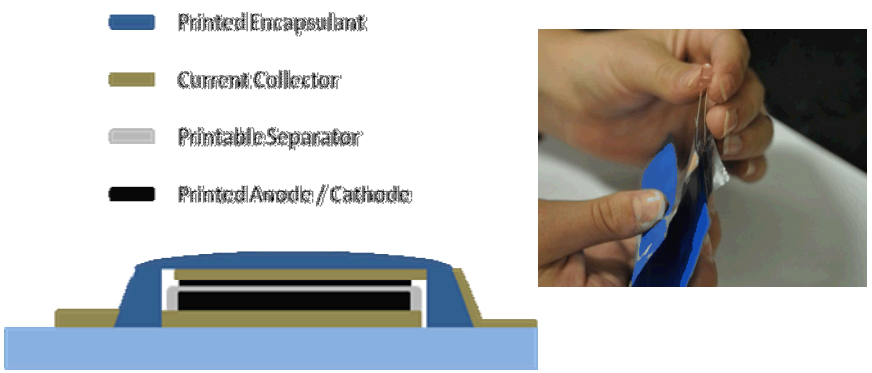
1) NZCF #1: $Ni_{0.530}Zn_{0.350}Cu_{0.120}Fe_{1.88}O_{3.82}$
2) NZCF #2: $Ni_{0.510}Zn_{0.350}Cu_{0.140}Fe_{1.86}O_{3.76}$
3) NZCF #3: $Ni_{0.490}Zn_{0.350}Cu_{0.160}Fe_{1.84}O_{3.76}$
4) NZCF #4: $Ni_{0.204}Zn_{0.612}Cu_{0.204}Fe_{1.98}O_{3.99}$
5) NZCF #5: $Ni_{0.170}Zn_{0.640}Cu_{0.200}Fe_{1.98}O_{3.98}$

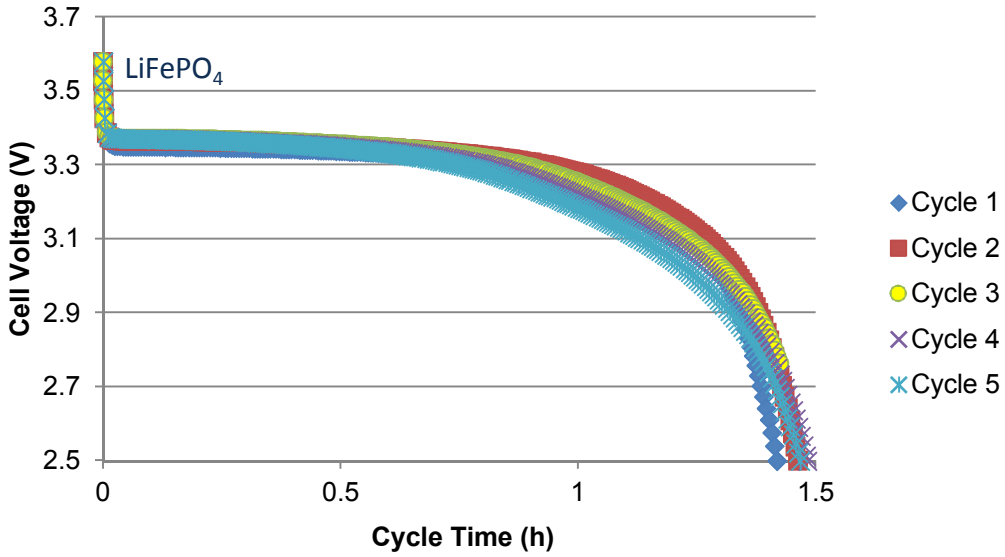


Courtesy: Chris DiAntonio, SNL

Direct write printed batteries

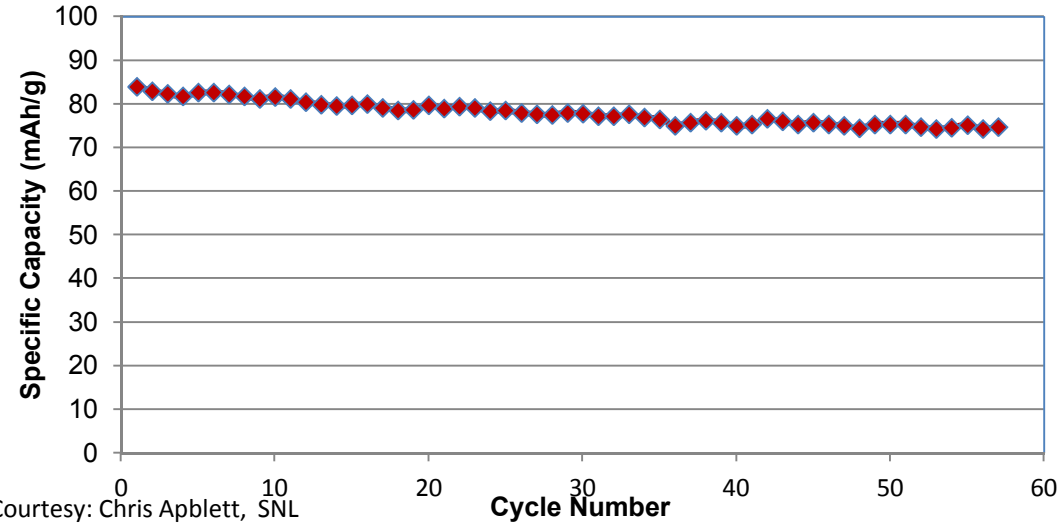
Cathode Cycling – Robocast Printed Device





- Capacity: 75 to 115 mAh/g
- Minimal degradation in performance

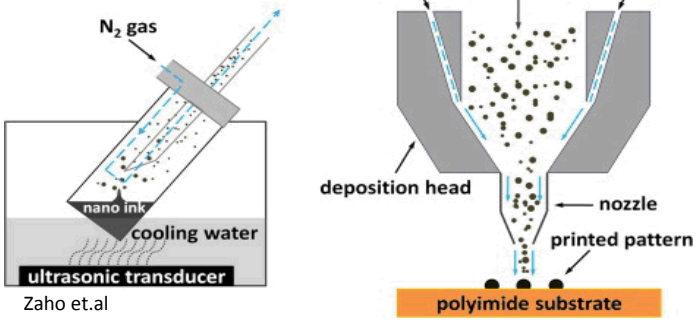
Capacity Loss With Increasing Cycle Number



Courtesy: Chris Apblett, SNL

- 75% capacity retention after ~60 cycles / 2 weeks of continuous cycling
- Retention of capacity does fade as rate increases
- Very good retention for long term applications

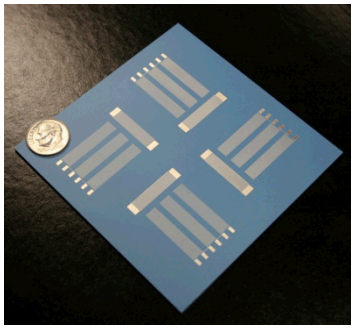
Direct Write Printing by Aerosol Jet

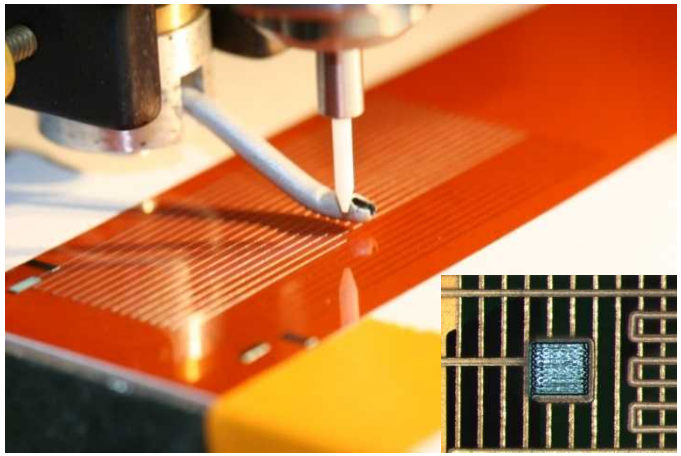


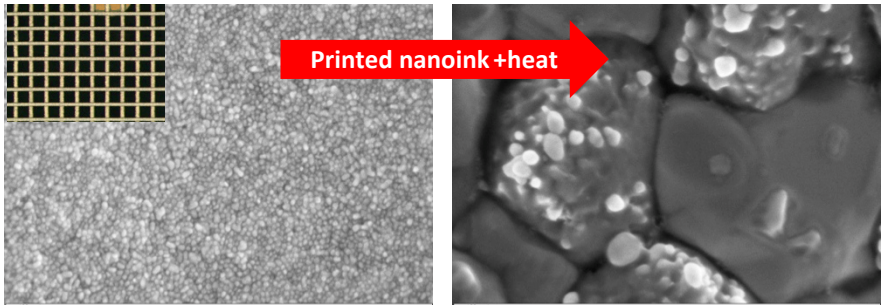
Zaho et.al

Aerosol Jet Printing Method (Optomec)

- Aerosol can be focused using inert gas streams and a small nozzle
- Atomization of liquid ink to produce a dense aerosol mist
- Line widths as narrow as 10 µm with 0.5-3 µm heights (silver nanoink)
- Broad materials compatibility
- Expanded post processing capabilities
- Rapid design iteration



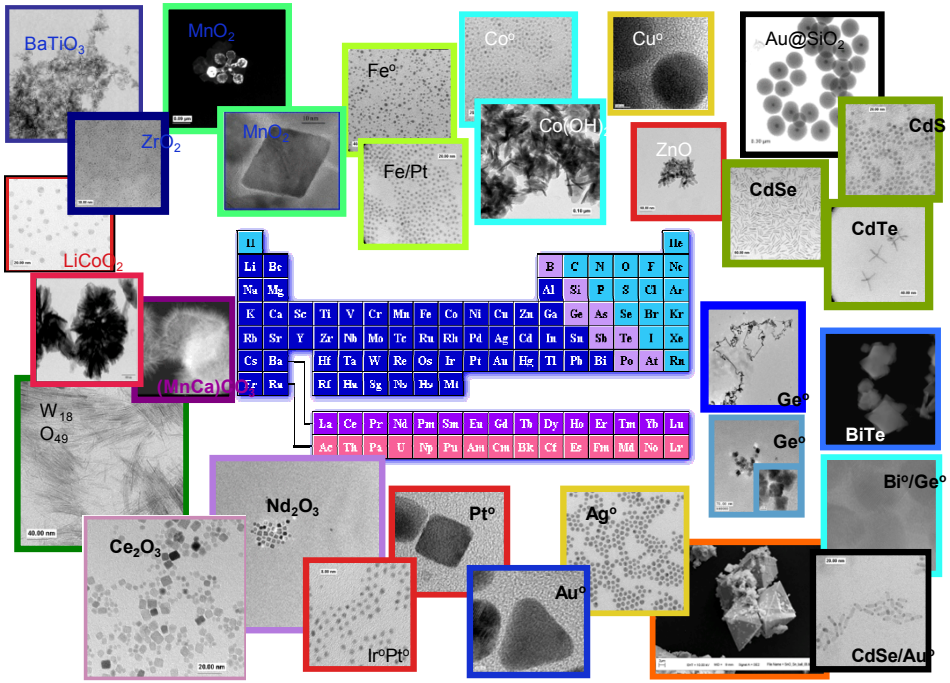


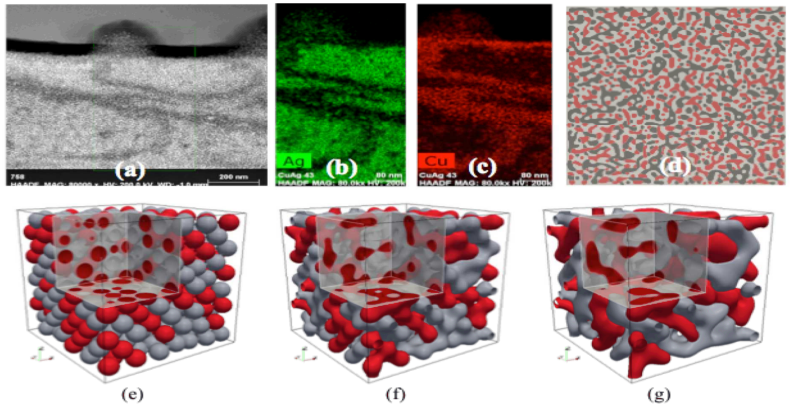


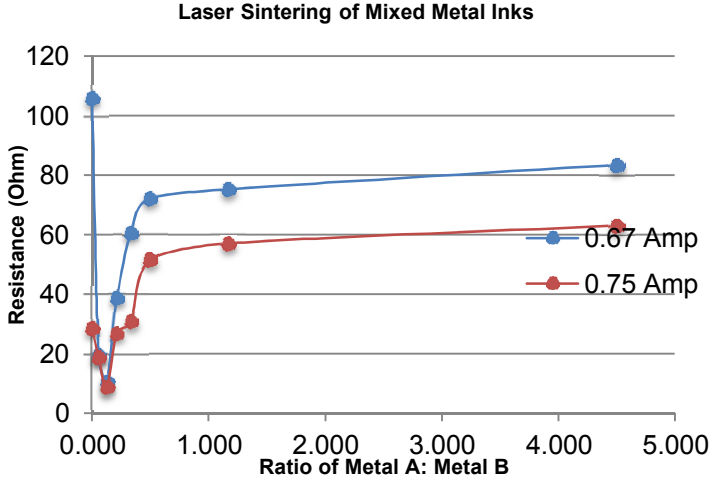
- DC and RF pathways for interconnect and antenna applications on planar or arbitrary surfaces
- Strain and crack sensors for structural health monitoring, resistance temperature devices (RTD)
- Integration of packaged components with external sensing networks for value added functionality

Fundamental research supporting additive manufacturing and digital printing

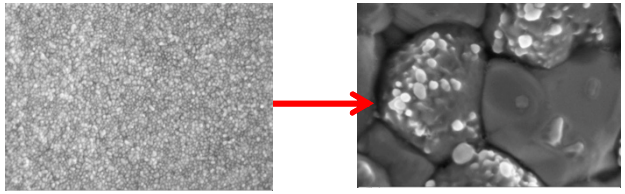
The development and study of tailored materials enable prototyping of functional components using Direct Write methods

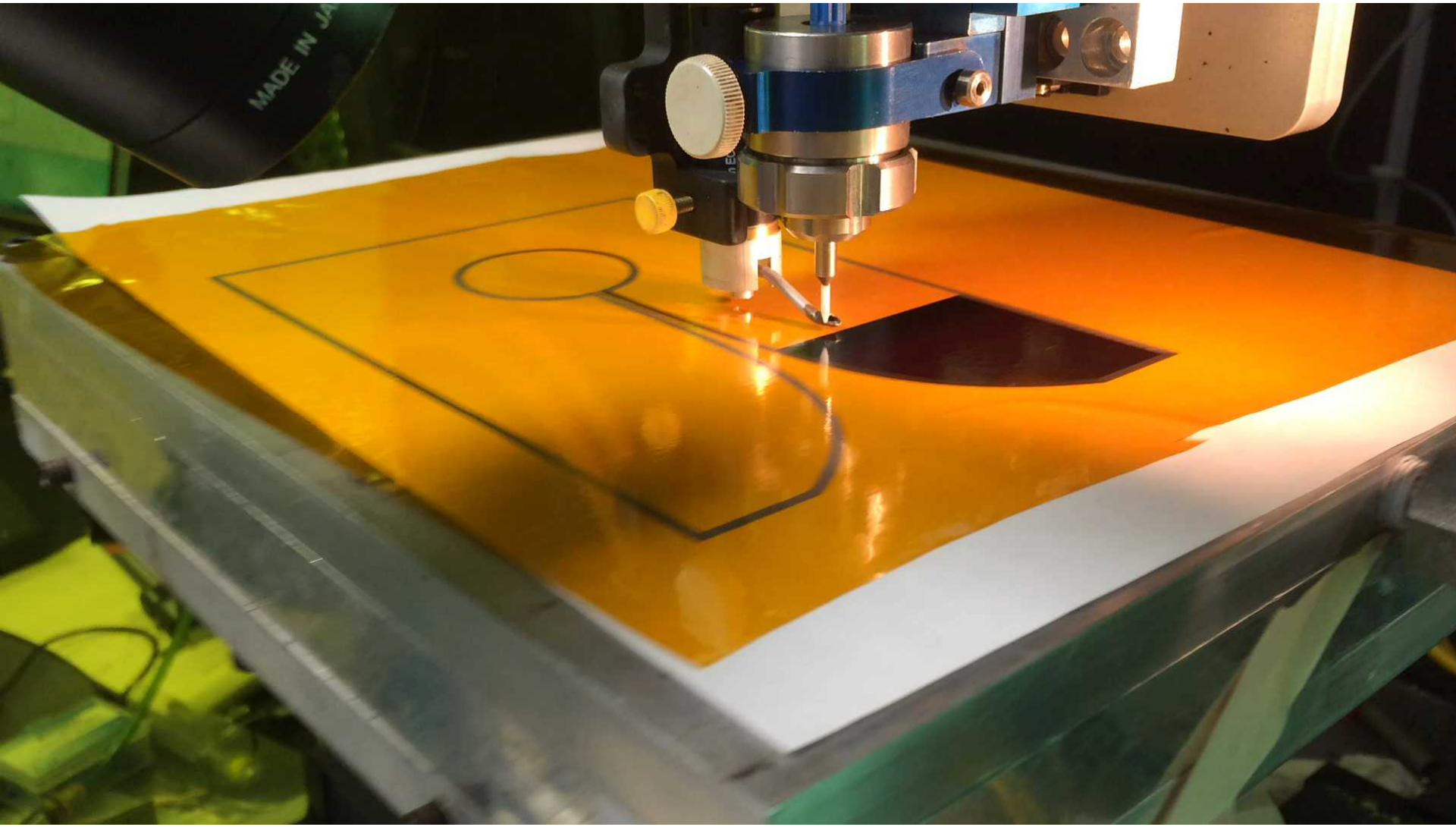




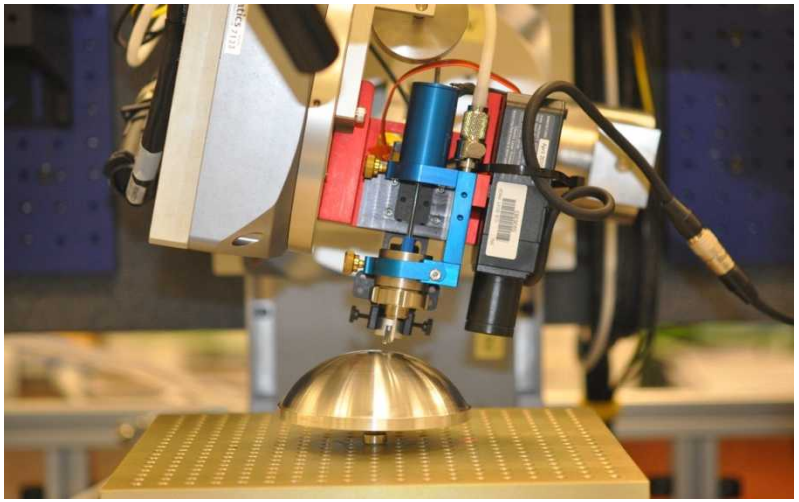


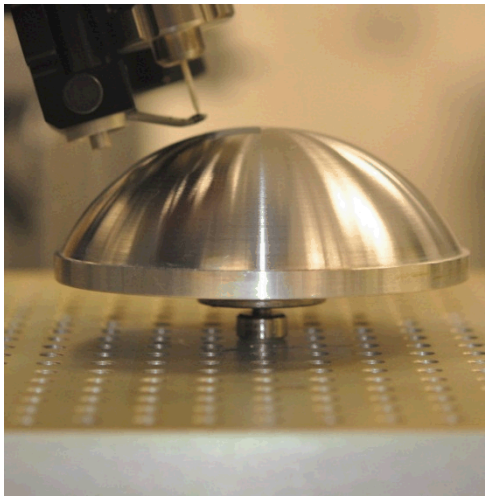
Curing metal inks changes functionality!

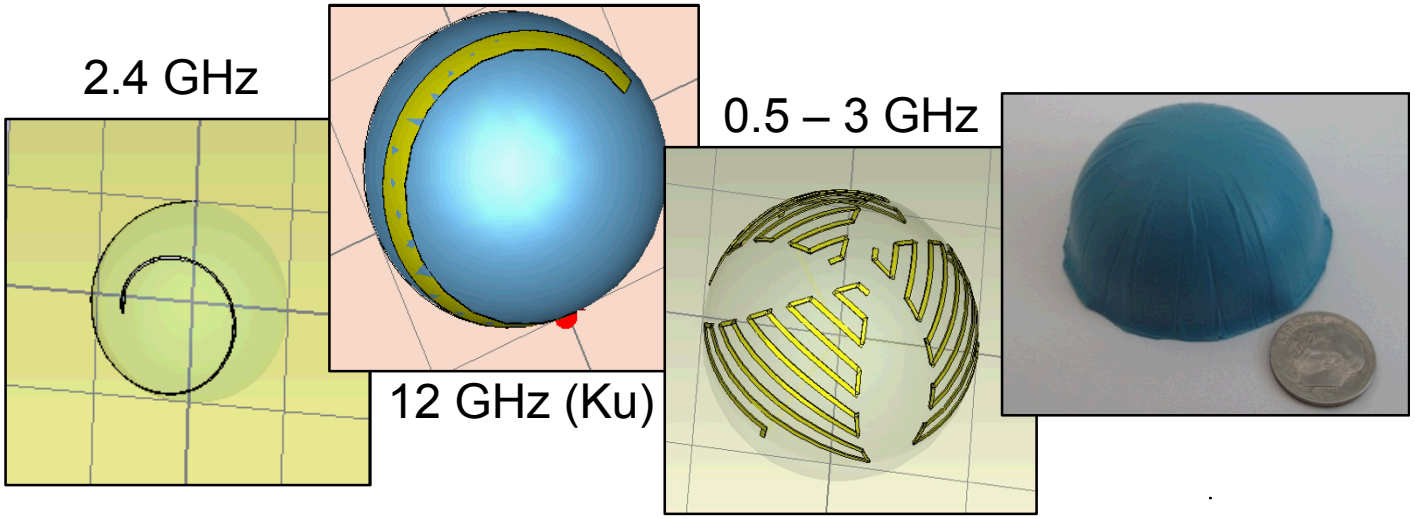



MADE IN

Direct Write and Conformal Printing



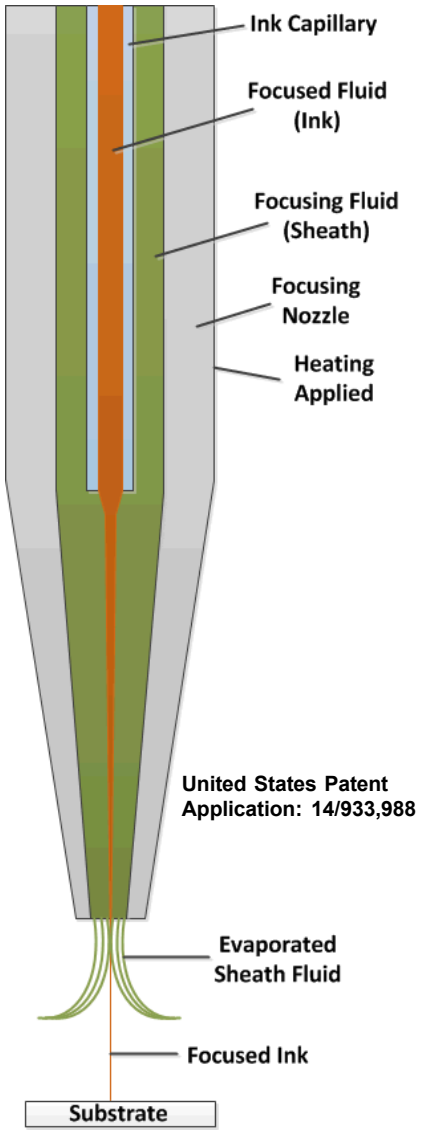


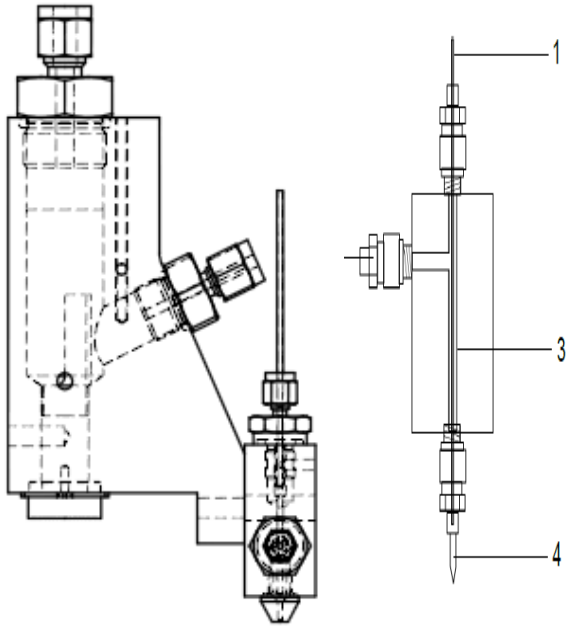


Goals:

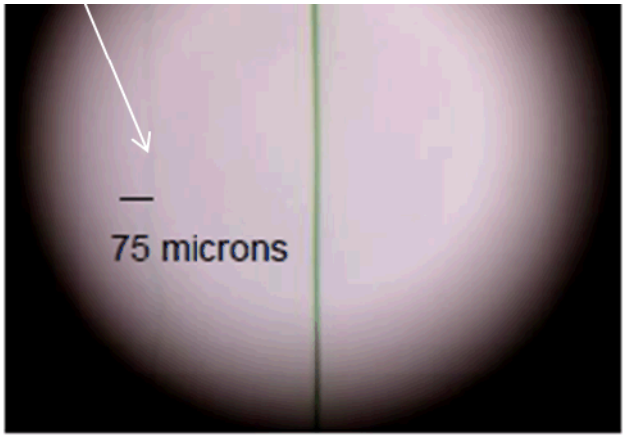
- Fabricate non-planar LTCC components
- Design antenna using conventional design tools and translate to function appropriately for Ku or Ka band operation
- Print antenna in Ag using SNL 6-Axis aerosol jet printing capability

Developing new direct write methods to address known limitations

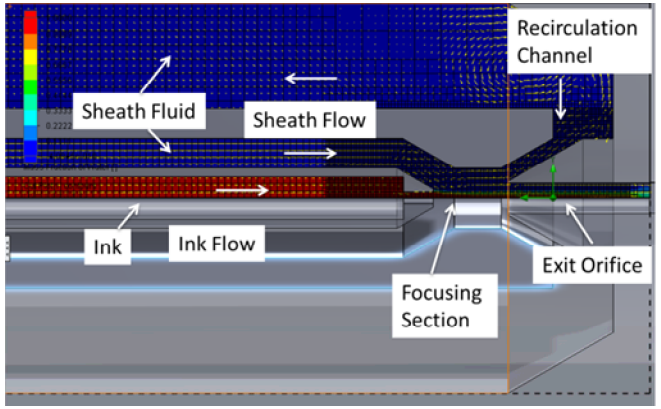




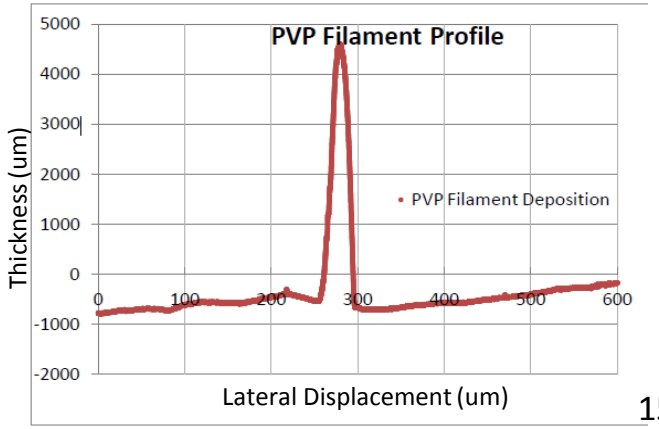
Deposition tool (above) Two Fluid printed segment (below)



Two-fluid printing technology may enable printing of insulated conductors and clad optical interconnects

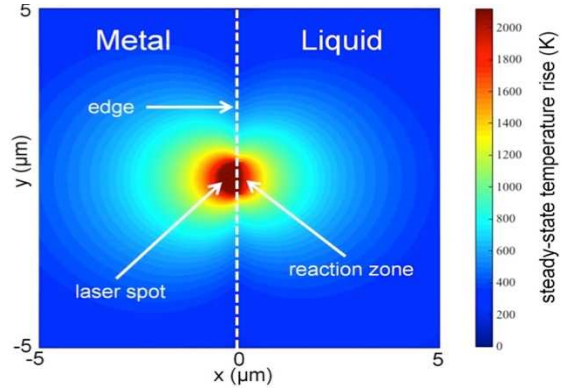


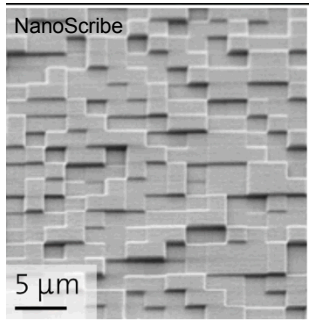
Computational Fluid Dynamic Simulation

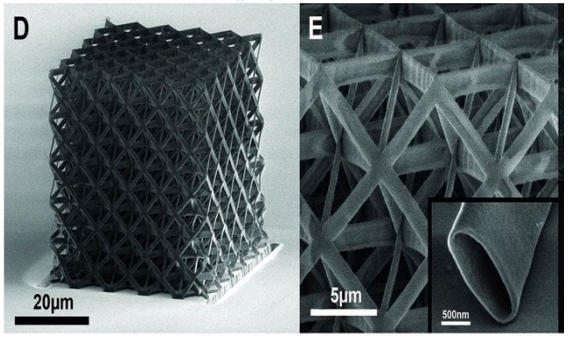


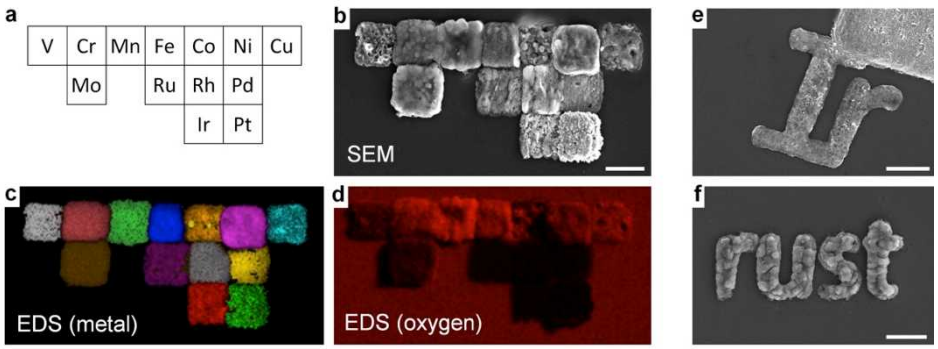
Trading complex lithography processes for two photon and direct laser write methods enable design freedom and shorten development time

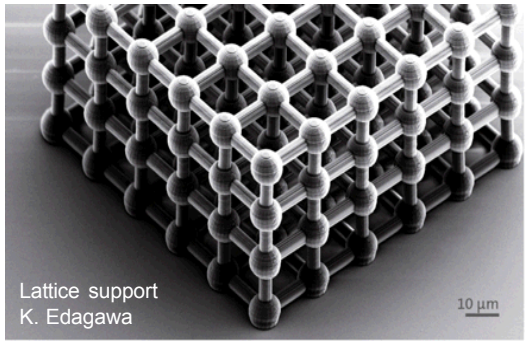
Two photon and direct laser write processes provide the finest level of detail attainable with a direct digital printing process

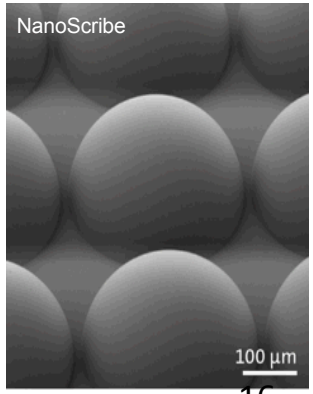












R&D Gravure/Flexo


Gravure


Gravure


Meter Bar

- Gravure, gravure offset, flexographic printing
- Low fluid consumption (1.5 ml)
- High printing speed (5 m/s)
- ***Multilayer alignment (<10 µm)***
- Printing hard/flexible substrates
- All parameters reproducibly adjustable
- Highest end, research grade instrument currently available

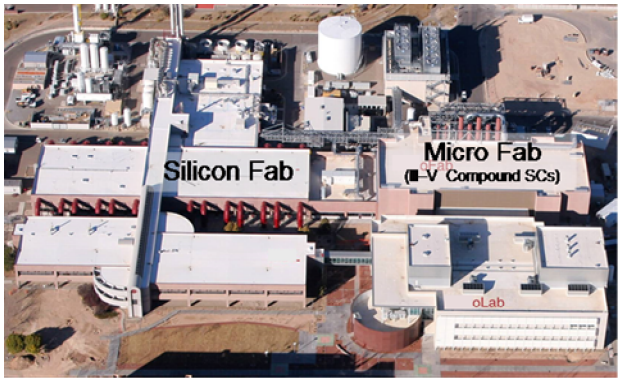
flexo

- Readily accessible (<10k) high quality printing tools.

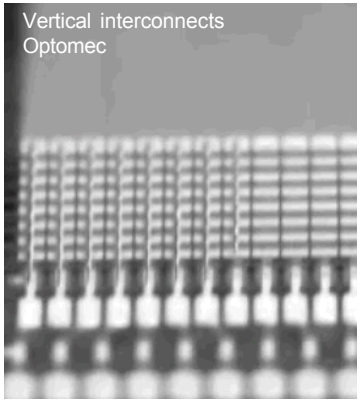
Leveraging the agility of printing technologies

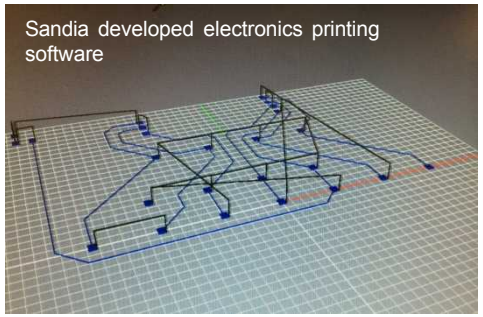
Sandia National Laboratories

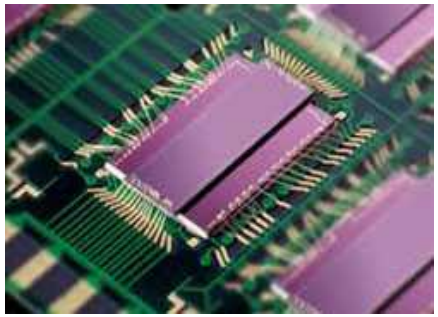
Scalable solutions to bridge R&D, prototyping, and trusted printing needs\

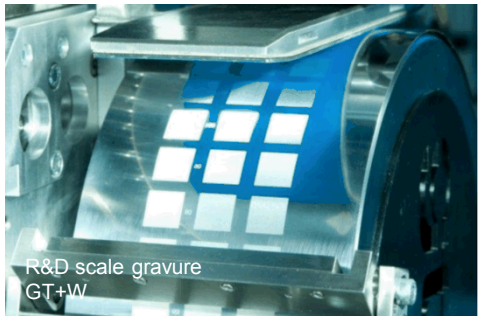



ASIC pick and place

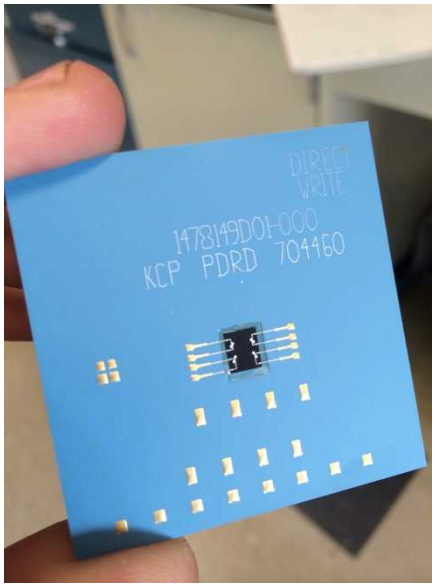

Vertical interconnects
Optomec


Sandia developed electronics printing software




R&D scale gravure
GT+W


Integrated conformal antennas
Optomec



Sandia National Laboratories

QUESTIONS?

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