SAND2019-1539PE

Printed Electronics Capabilities at Sandia National Laboratories and Opportunities for Partnering



PRESENTED BY

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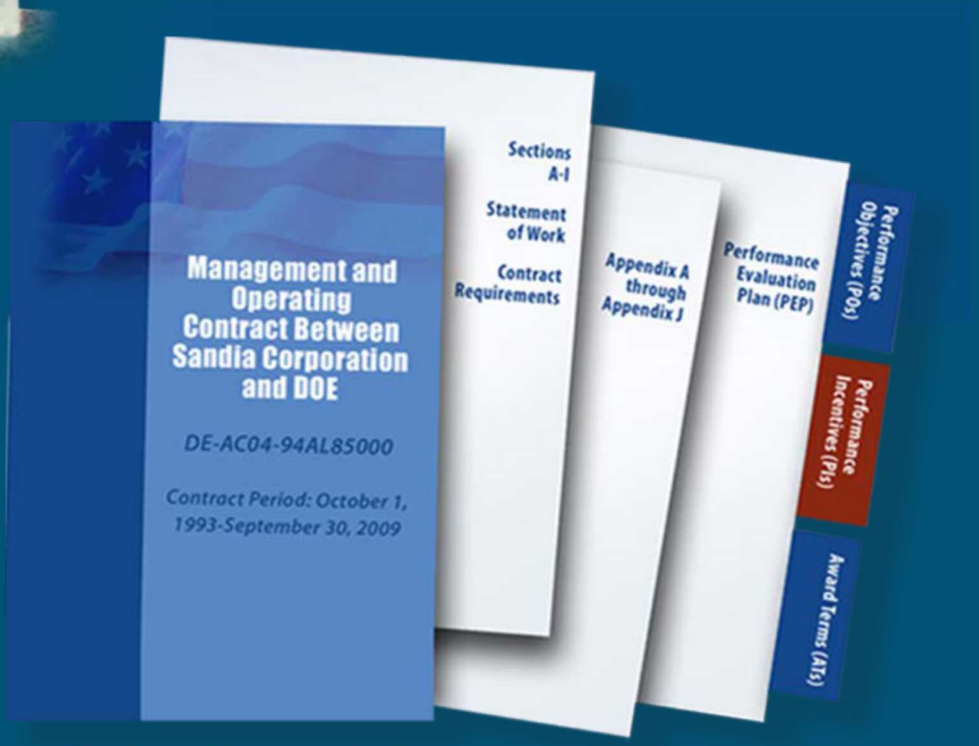
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Sandia's Governance Structure

Government owned, contractor operated

Sandia Corporation

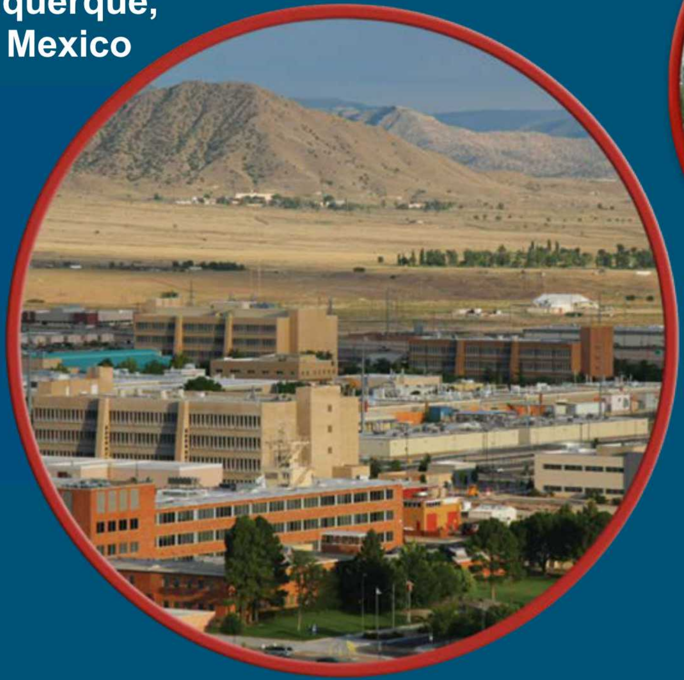
- AT&T: 1949–1993
- Martin Marietta: 1993–1995
- Lockheed Martin: 1995–present
- Honeywell/NTESS: 2017



Federally funded research and development center

Sandia’s Sites

Albuquerque,
New Mexico



Livermore,
California

Tonopah, Nevada

Waste Isolation Pilot Plant,
Carlsbad, New Mexico

Pantex, Texas

The Mission Has Evolved for Decades

1950s
Production engineering & manufacturing engineering

1960s
Development engineering

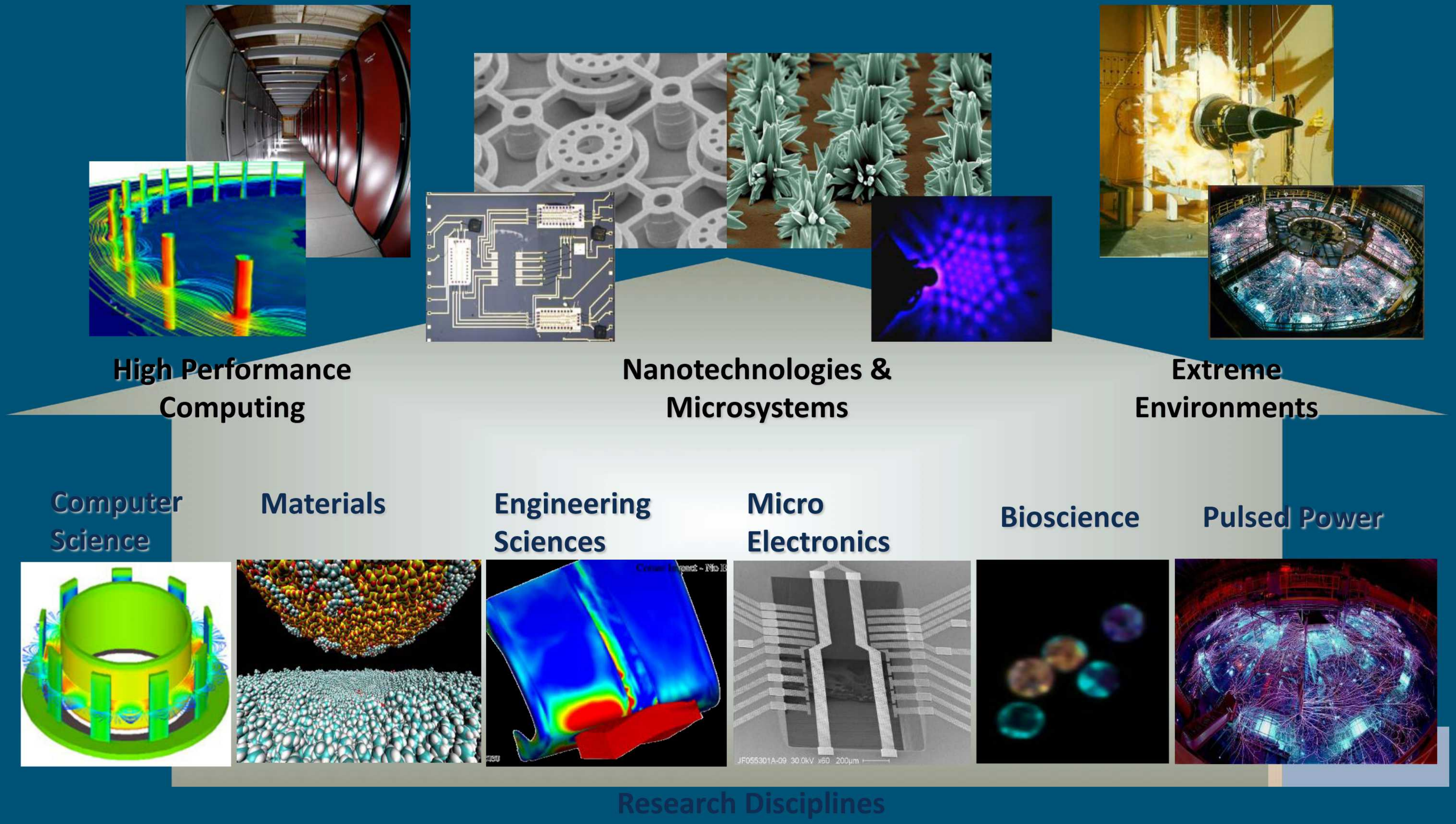
1970s
Multiprogram laboratory

1980s
Research, development and production

1990s
Post-Cold War transition

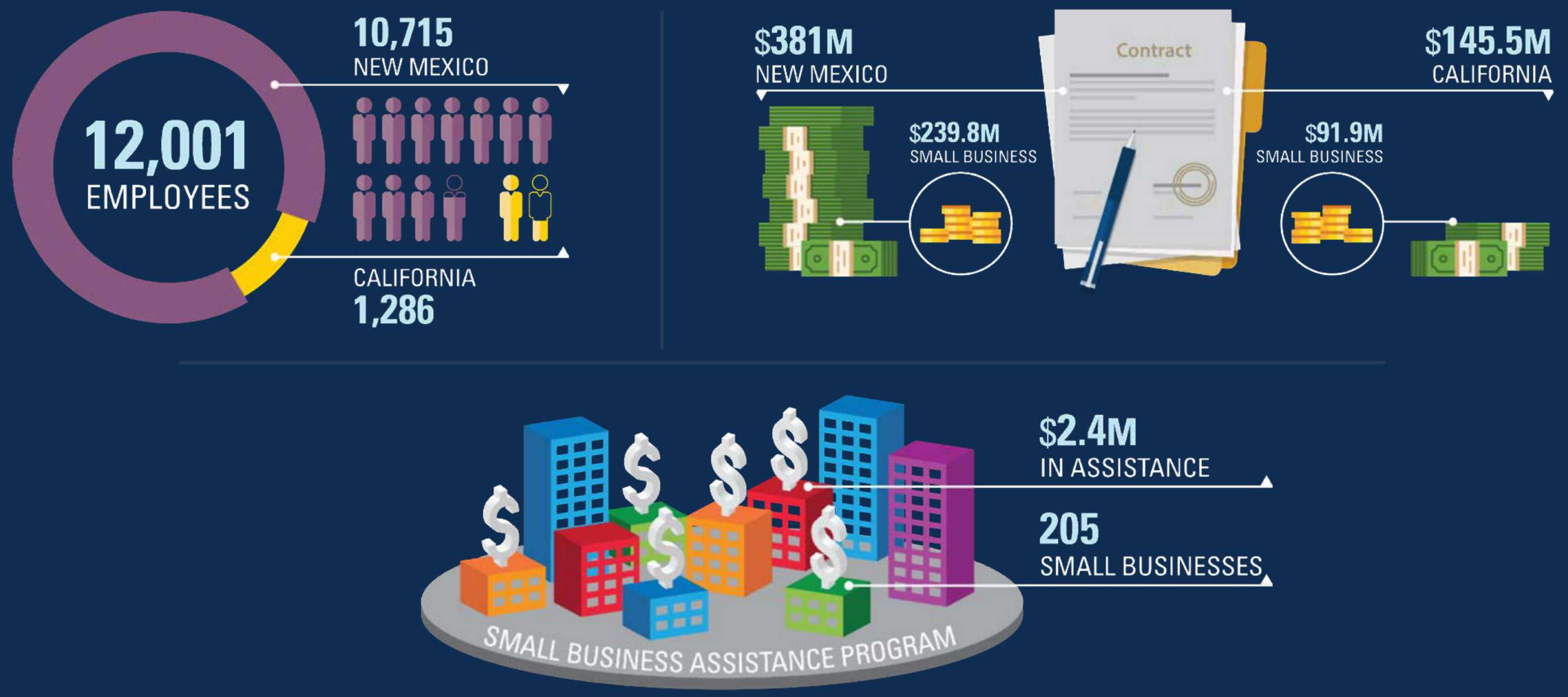
2000s
Broader national security challenges

Research Disciplines Drive Capabilities



FY 2016: Impacting the local economy

Workforce: 12,001 employees (10,715 NM, 1,286 CA)



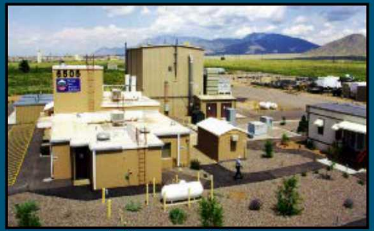
Sandia Materials & Process Science

- ***Fundamental Materials & Process Science***
  - Develop/integrate theoretical insights, computational simulation tools, and experiments to provide foundational, predictive understanding
  - Develop innovative new materials and process technologies
  - Create advanced materials analysis & process diagnostics tools
- ***Materials & Process Advanced Development***
  - Advanced & exploratory materials & process development
  - Production process development & technology transfer
- ***Materials Engineering/Production Support***
  - Materials & process selection/optimization
  - Problem solving, production support
  - Understanding & quantifying the margins

Multiple Large Materials R&D Facilities

Processing & Environmental Technology Laboratory

Center for Integrated Nano Technologies



Thermal Spray Research Laboratory

Advanced Materials & Processes Laboratory

Ion Beam Laboratory

Integrated Materials Research Laboratory

Microsystems Science & Technology Center

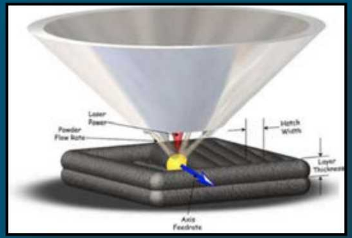
Advanced Materials Laboratory

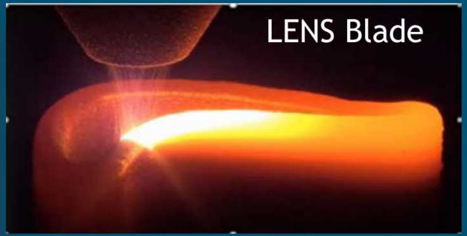
30+ Years of Sandia AM Technology Development & Commercialization

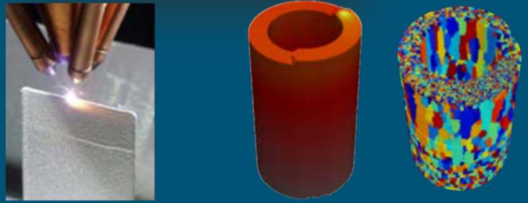
FastCast *

Development Housing

Laser Engineered Net Shaping LENS®

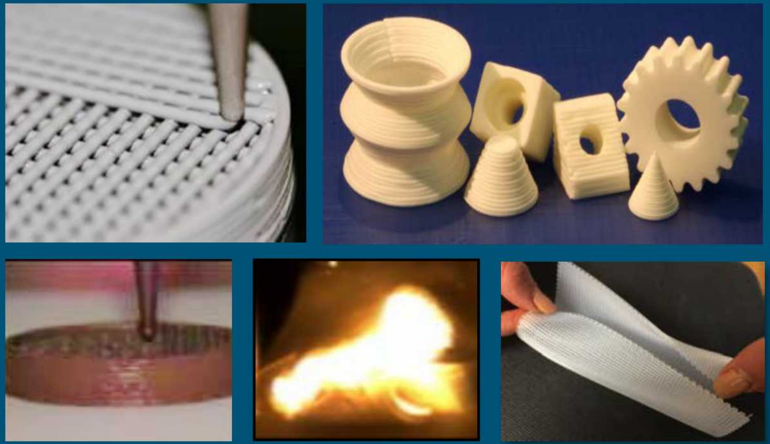






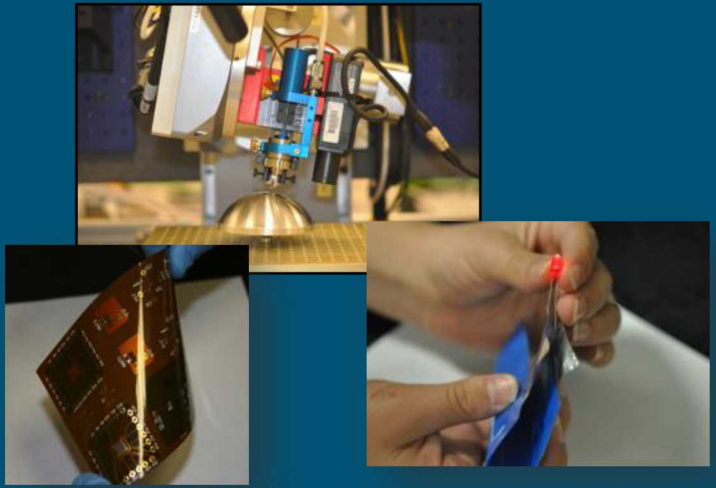
Grain morphology prediction

Robocasting *



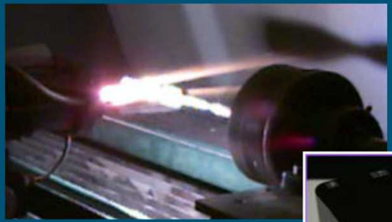
Ceramic, energetics, elastomers

Direct Write



Conformal Printing, flexible electronics, power sources

Thermal Spray

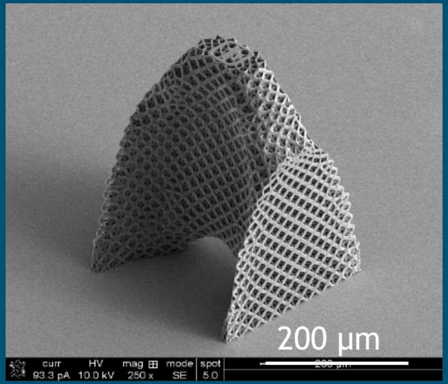


Spray-formed Rocket Nozzle

Metal on Plastic

Micro-Nano Scale AM

Lattice Structure



* = Licensed/Commercialized Sandia AM technologies

Underline = *Current Capability/Activity*

Advanced Materials Laboratory

Advanced Materials Laboratory (AML) – a Sandia-leased facility on the campus of the University of New Mexico

Original Vision: Foster substantive collaborative/partnering relationships in material science with UNM

Strategic Advantages:

- Access to students
- Greater opportunity for collaborations with UNM faculty
- Access to campus resources – equipment, library, computer resources
- Funding sources not readily available to Sandia (NSF)
- Technology transfer
- Joint purchase/maintenance of novel instrumentation

The Advanced Materials Laboratory, a part of Sandia National Labs since August, 1992
29,295 sq ft. (~14,000 sq ft lab space)

Developing materials science and engineering technology in the National Interest

AML Mission, Focus, and Vision

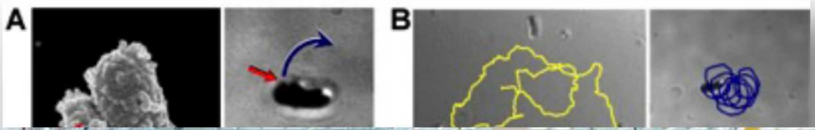
- The Advanced Materials Laboratory (AML) provides unique materials discovery solutions coupled with materials demonstration/deployment.

- AML’s materials focus centers around synthetic chemistry routes with novel precursors and catalysts to explore new materials with solvo-thermal, solution-precipitation, and sol-gel routes.

- AML’s rapidly advancing materials processing capability enables materials delivery ready for functional prototyping

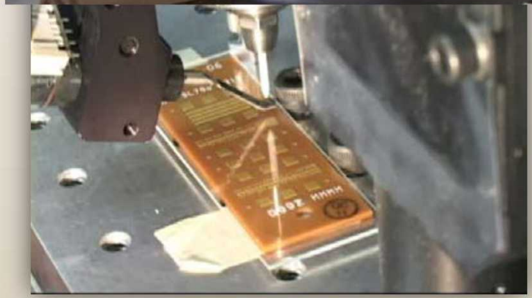
  Integrated materials synthesis and materials processing breadth unique to the complex

The AML has a wide range of capabilities important to Sandia's missions



Synthetic Chemistry

embly

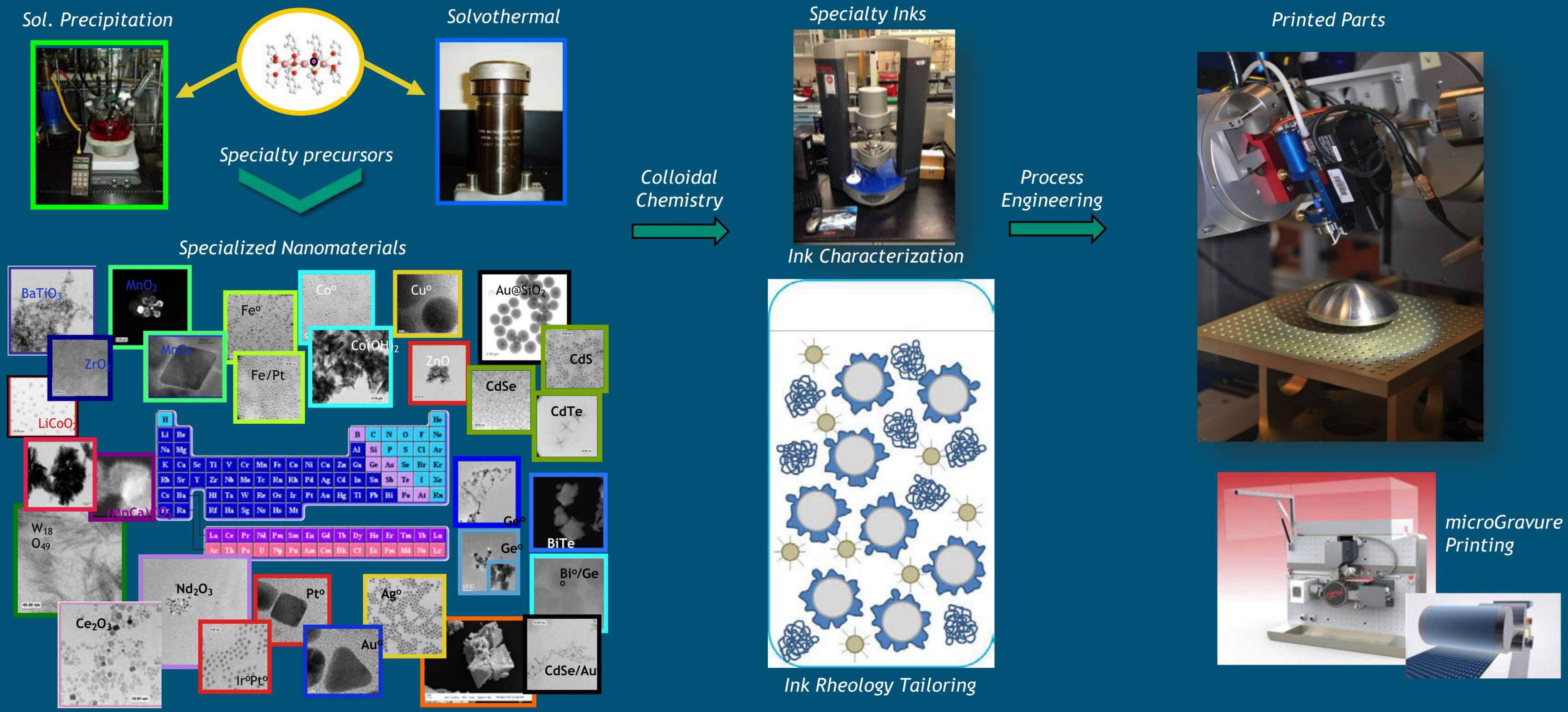


Characterization
- Diffractometry: XRD, XPS
- Thermal (TGA, DSC)
- Spectroscopy (mass, FTIR, ICP)
- Multispectral ellipsometer

- Fibers (electrospinning)
- Bulk materials (sintering)
- Multiphoton lithography
- Direct/aerosol write, inkjet
- Gravure/flexography

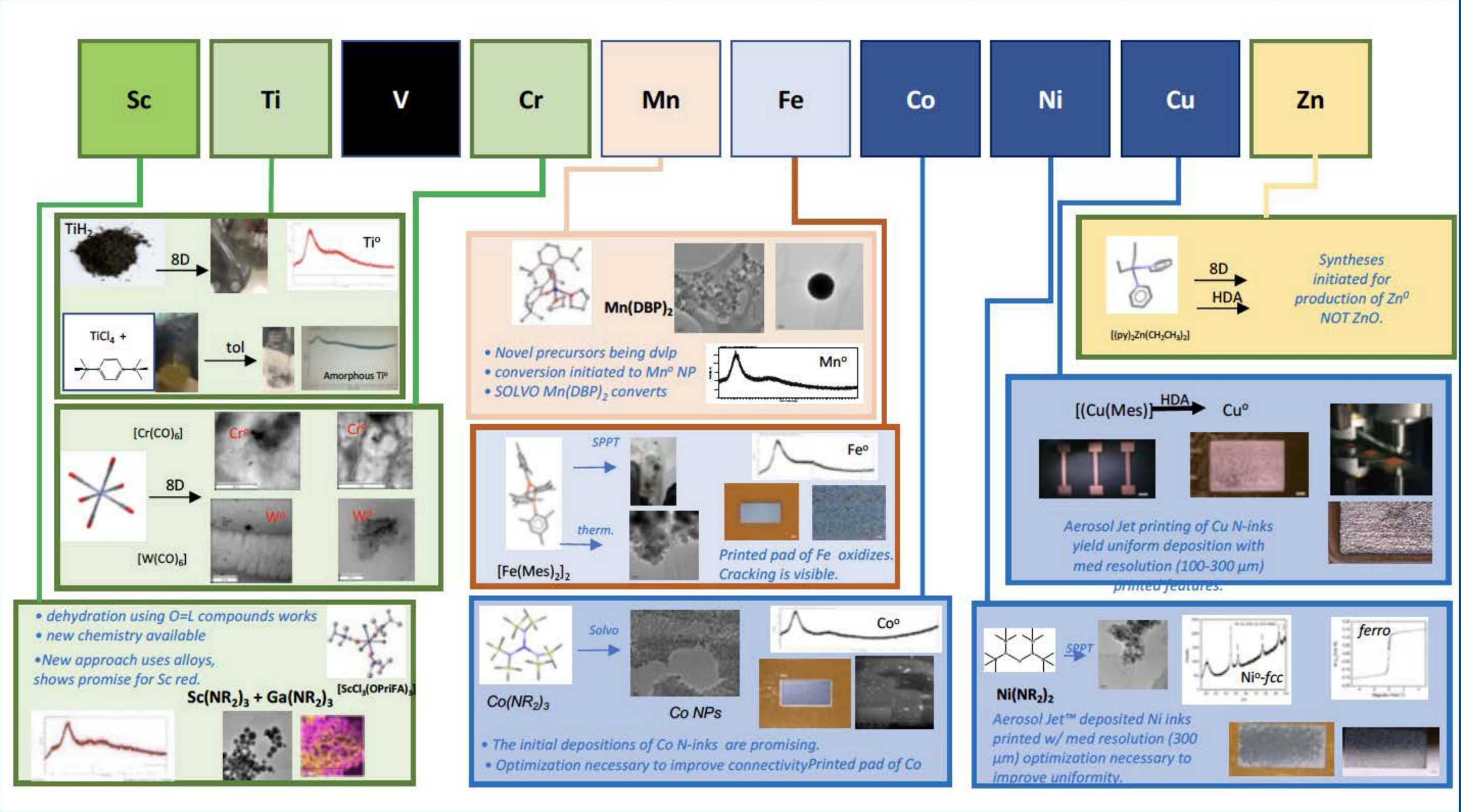
AM with Particulate Inks at Sandia…*Why ink-based processing?*

The electronic devices required for energy storage, power distribution, sensing, and RF needs require materials flexibility, low cost fabrication processes, and lean development cycles. Digital printing and templated deposition processes leverage the flexibility provided by ink based printing for advanced component research and development.



Printed Electronic Materials Development Program

Materials development initiatives are underway to address system-level incompatibilities, materials reliability (e.g. corrosion resistance), and an initial qualification framework to support acceptance and use of printed electronic materials.

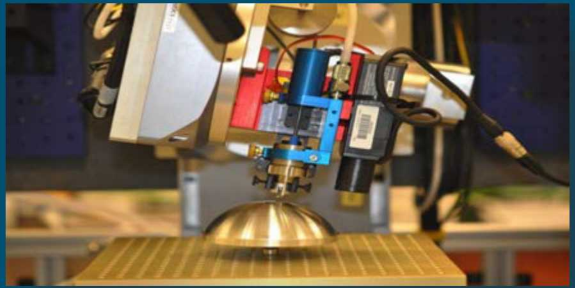


Ink Based Processing Capabilities

Our deposition, characterization, and processing capabilities enable tailored support to meet diverse mission needs


NOVACENTRIX

PLASMA ETCH
PROGRESS THROUGH INNOVATION


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

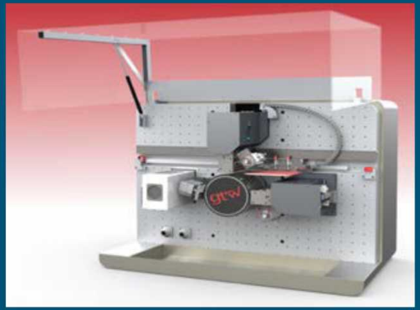
nScrypt

nanoscribe

Nordson EFD

Sandia National Laboratories

FUJIFILM

RK

gtw

HARPER
HarperScientific Division



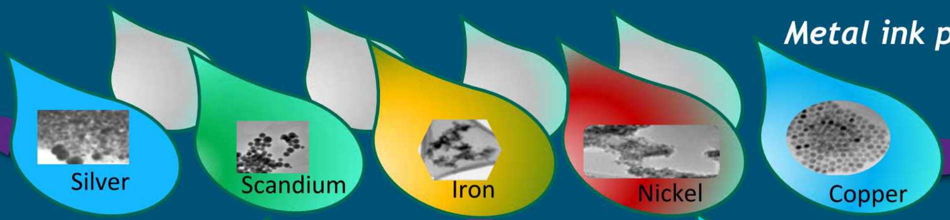
AST PRODUCTS INC.

KEYENCE

BRUKER

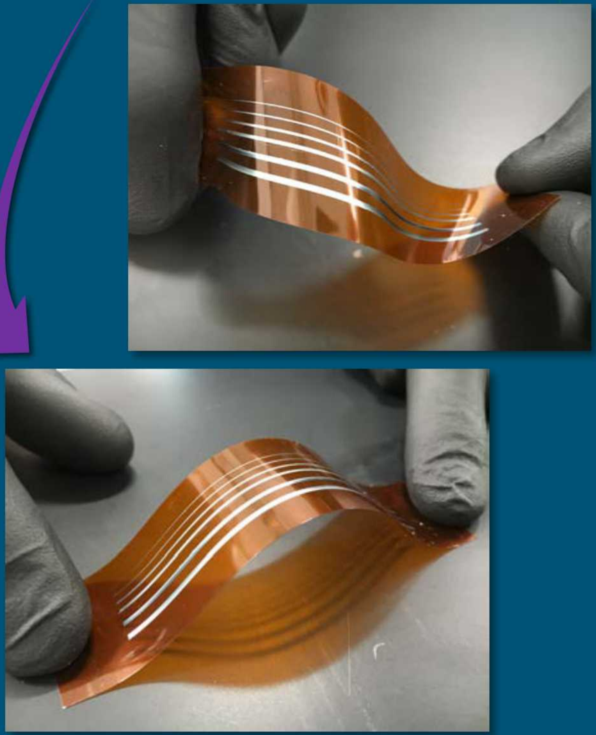
Printing on Flexible Surfaces With Enabling Nano Inks

Metal ink precursors

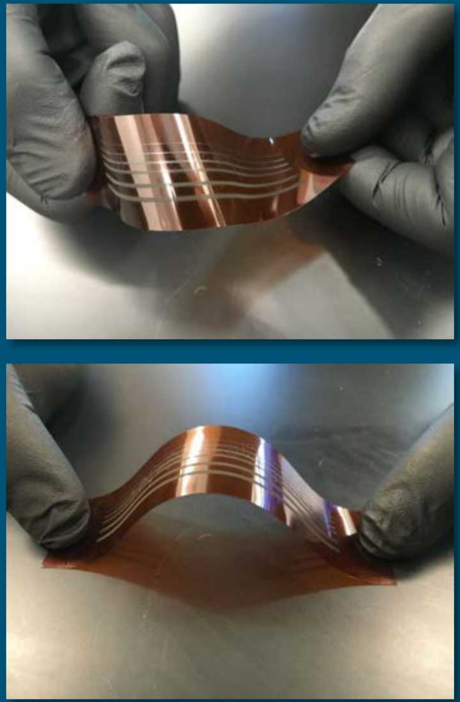


In progress

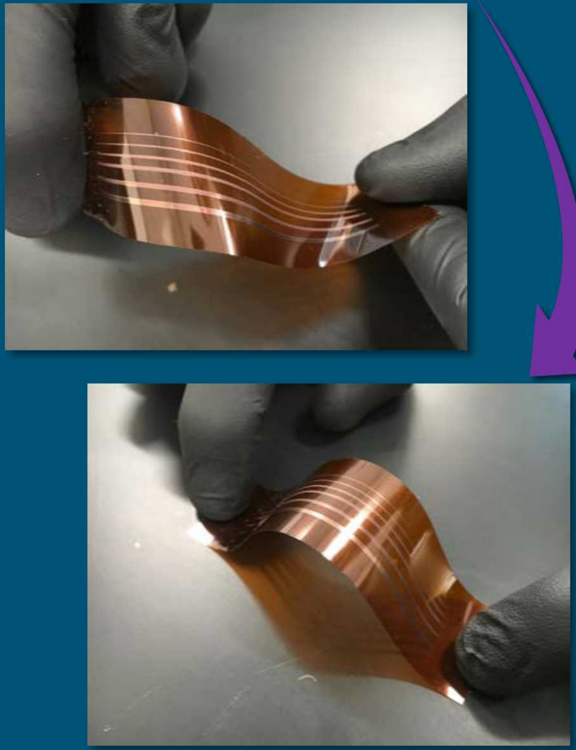
In progress



Printed cable using silver ink precursors
1.5-2 X's Bulk Resistivity



Printed cable using iron ink precursors
Permeability TBD, alloys to be developed

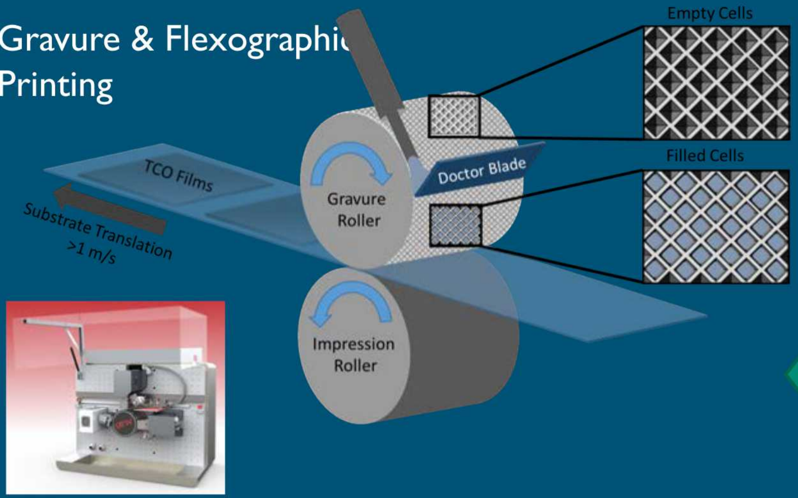


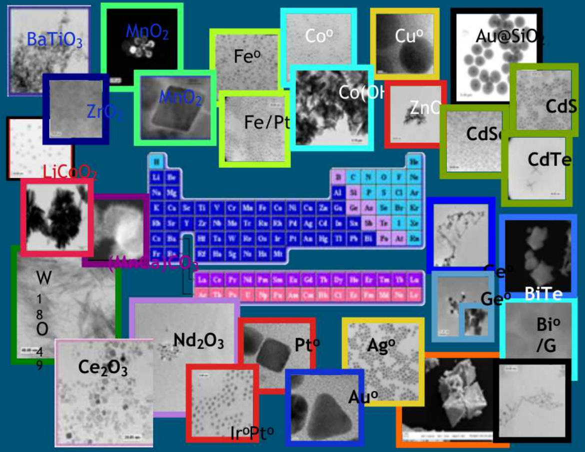
Printed cable using copper ink precursors
3.5-5 X's Bulk Resistivity

Printing Inks Carry Functionality

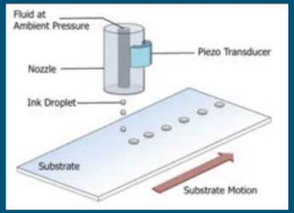
The strong suit of printed systems is the integration of diverse materials, however process requirements can influence material selections.

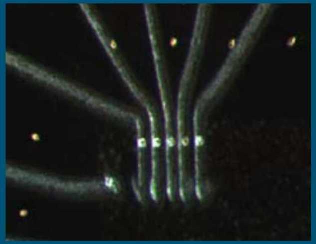
Gravure & Flexographic Printing

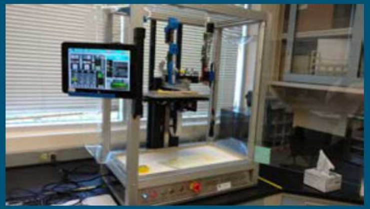




MATERIALS







Direct Write (DoD, DW, Aerosol)

	Gravure	Direct write
Resolution	< 5 µm	< 30 µm
Speed	1 m^2/s	< 1m^2/hr
Ink Viscosity	1-500 cP	1 cP – 10^4 P
Method	Contact	Non-Contact

Inkjet, aerosol deposition, micro-extrusion , and gravure are complementary methods for low-cost fabrication

Sandia Mission needs for Printed Electronics/Photonics Legion, and Growing

Materials/devices for energy storage, generation, conversion.

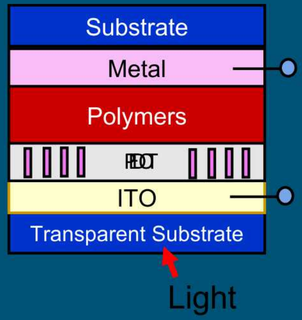
Application specific sensors (passive and active) – e.g. RF, stress, strain, EM, etc.

Electronics integrated with 3D metal and ceramic components

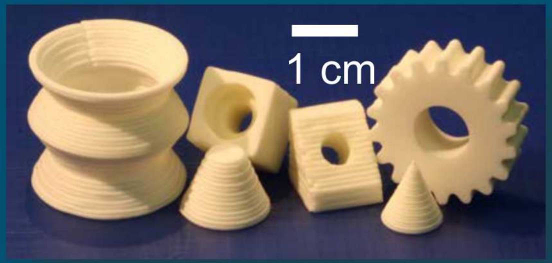
Printed electronics – packaging, interconnects (cables and connectors)

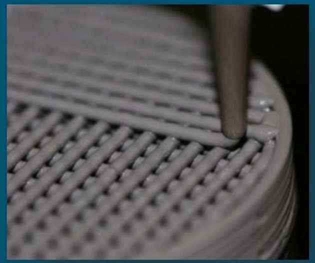
Precision interconnects and FHE. Integration of Si-CMOS devices with systems packaging, heterogeneous integration.

Energy Storage/Generation Materials

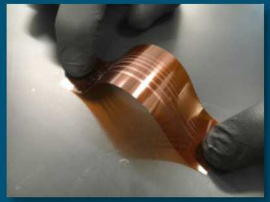


Ceramics

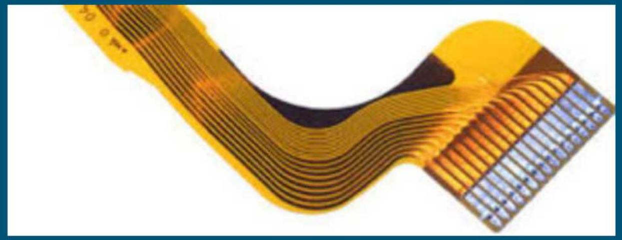




FLEX



Logic devices/Memristors

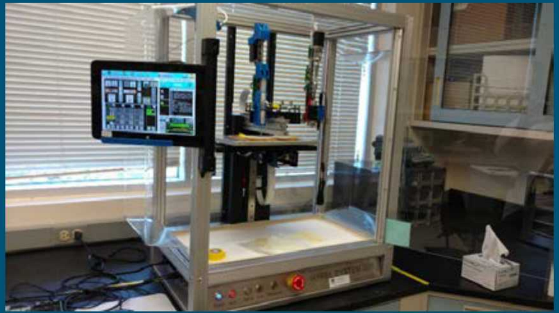


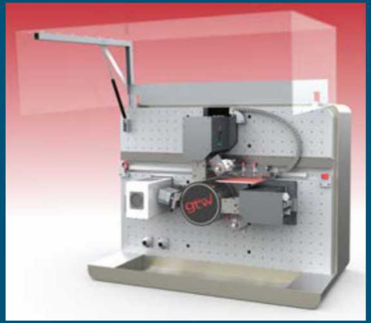
Why Sandia? Why Now? Why Partnership?

Manufacturing/Fabrication "Commons" at Sandia

- Silicon CMOS
- III – IV Semi
- Radiation hardened microelectronics
- Reactive ion etching
- Lithography of various forms (optical, imprint)
- 3D printing (polymers, metal)
- Advanced vacuum technologies
- Advanced CVD technologies (viz. ALD)
- Ionomeric polymers
- Metal and polymer Additive manufacturing
- *Polymer science and processing (Akron and others)*
- ***2D printing, printed devices (AFRL, and others)***
- ***Precision printing and liquid film coating***
- ***Modeling and simulation at all scales***

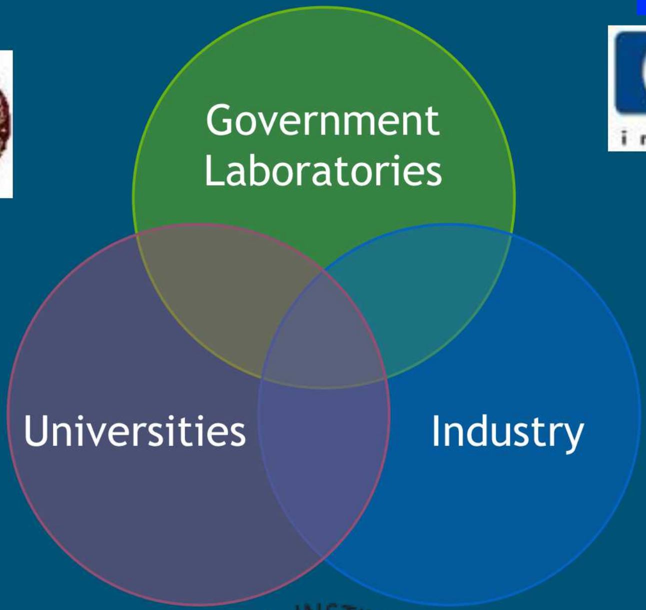
OPTOMEC
Production Grade 3D Printers... with a Material Difference





Sandia's commons are complimentary…..

Partnerships and Collaboration Accelerate Innovation



Doing Business with Sandia

Partnerships Agreements

Sandia National Laboratories

PRESENTED BY

Types of Agreements

Other Federal Agency Agreements (OFAs)

Cooperative Research and Development Agreements (CRADAs)

Commercial Licenses

Funds-in (Non Federal Enitity)

Designated Capability (DC)

User Facility (UF)

Cooperative Research and Development Agreements (CRADAs)

Governs collaborative R&D between SNL and industry

Can be 100% funded by partner, must include “in-kind” contribution

DOE approval required

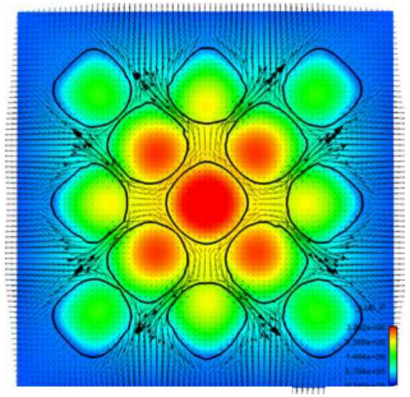
Each party can take title to its own CRADA generated IP

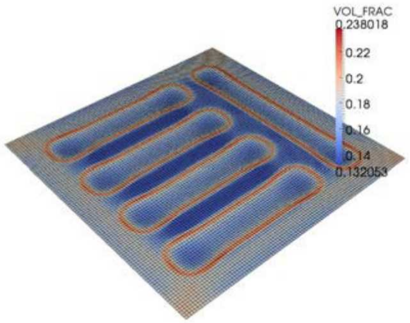
Partner has option to license joint inventions

Additional Slides

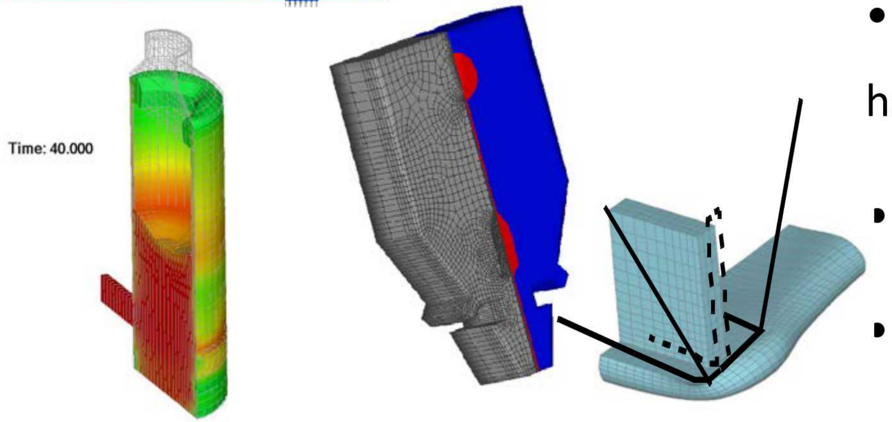
Research Group Capability: Goma 6.0

2014 R&D 100 Award Winner





- Multiphysics ***finite element*** code, suitable for both ***research*** and ***production***
- Fully-coupled ***free*** and moving ***boundary*** parameterization – ALE, Level Set, etc.
- Modular code; ***easy to add equations*** – currently has 170+ differential equations
- ***Open source***! Available at **http://goma.github.io**
- ***Goma 6.0. training*** is available on regular basis

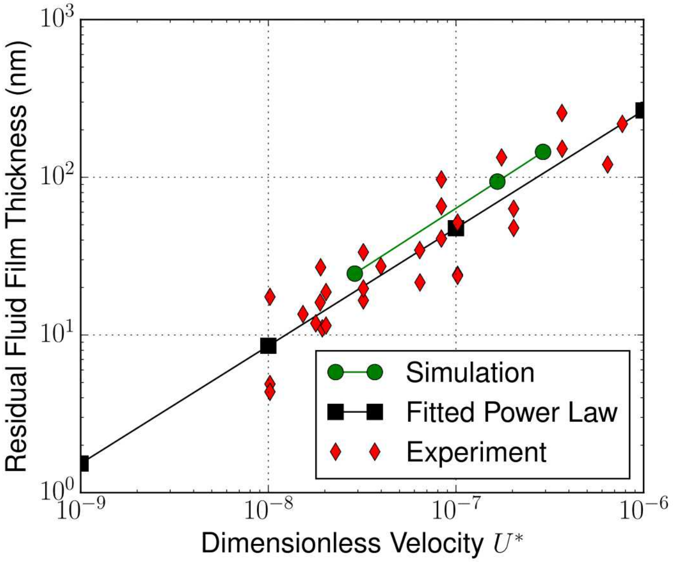


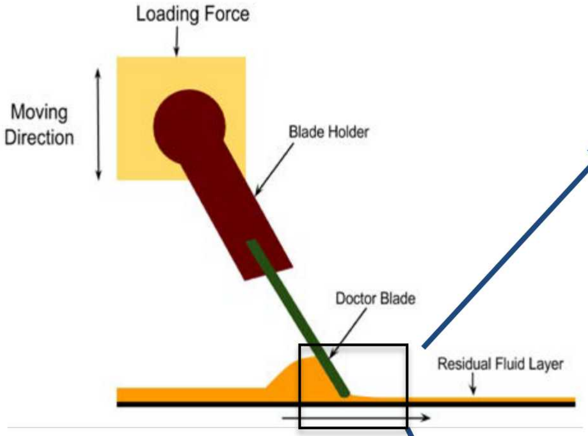
Goma has been used successfully in coating manufacturing for 2 decades!

…Also a competency in LAMMPS for colloidal rheology and self/directed assembly

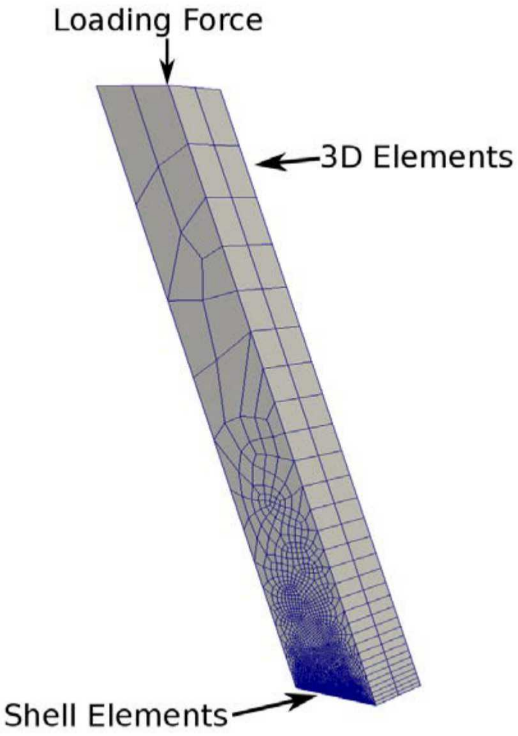
Computational model of doctoring in gravure printing

*Thrust: **P-2C Reliable Processes for High-Speed Printing***





Model predicts residual film thickness over speed and load– arguably the most important factor affecting resolution limits



Coupled Ink lubrication model

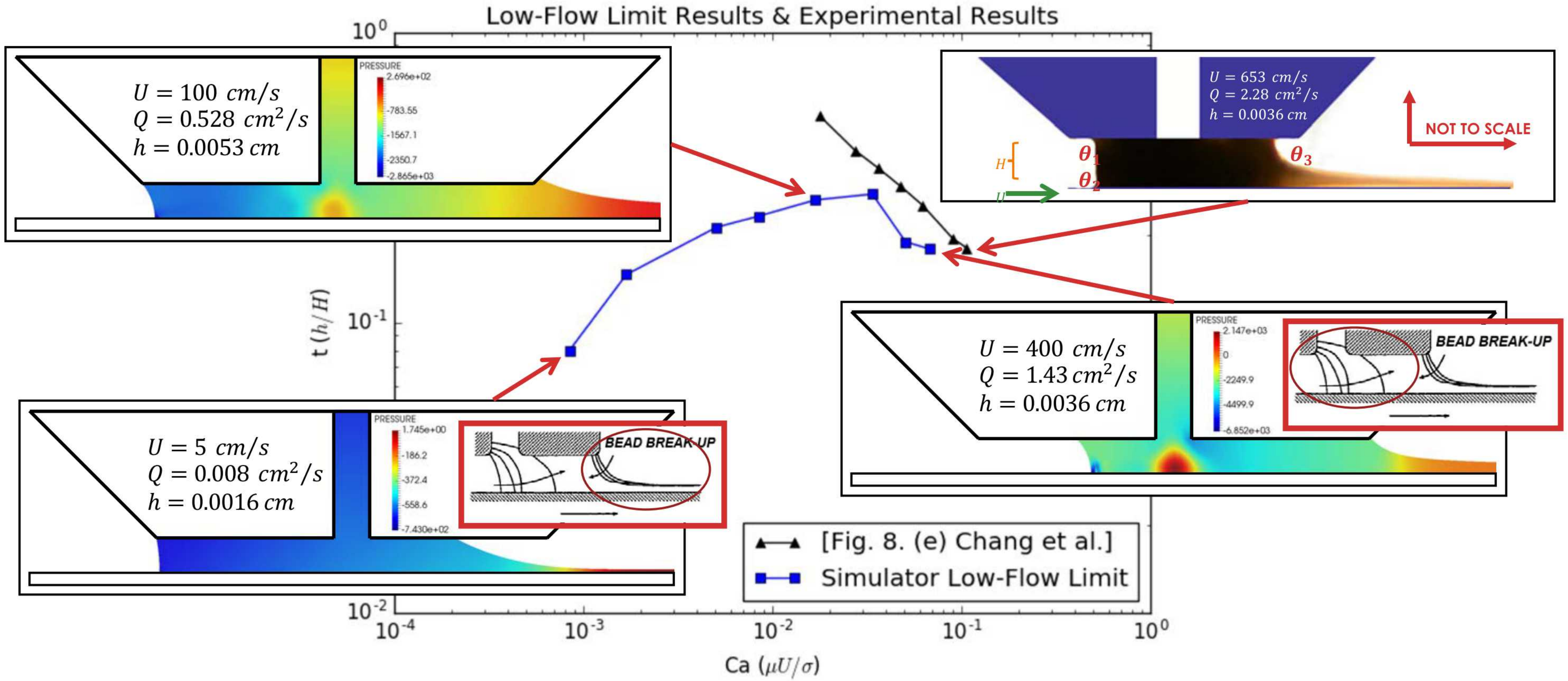
Hariprasad et al. 2016, J. Applied Physics, DOI: 10.1063/1.4945030

UNM NASCENT 3M P&G Sandia National Laboratories

Precision Slot-Die Coating

Low-Flow limit comparison to experimental results

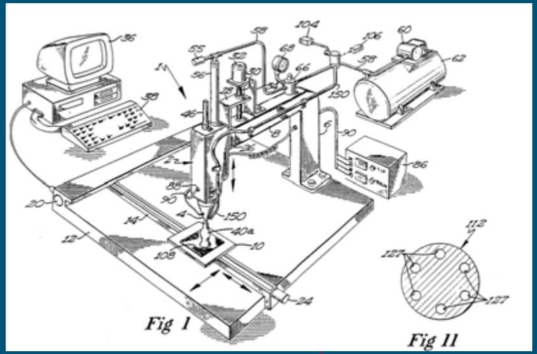
- Computational results reproduce experimental film thicknesses, meniscus topologies, and failure modes



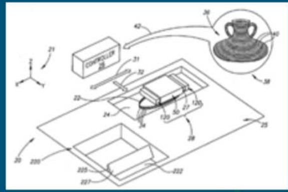
Low-Flow limit three region coexistence analysis

- Region 1 and 3 identified but region 2 not clear

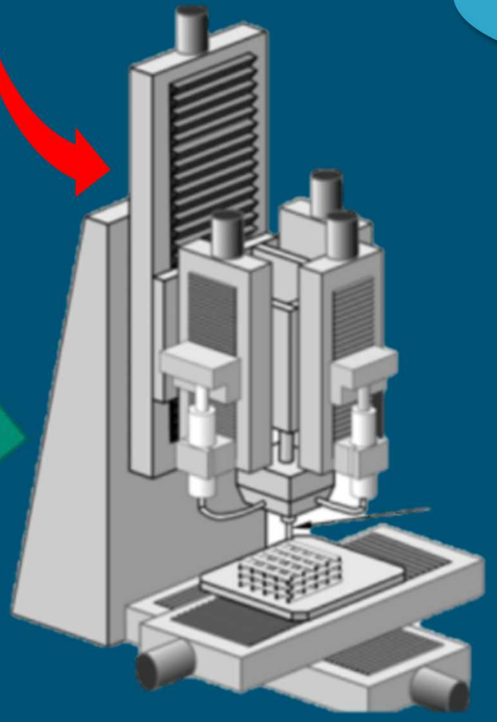
Direct ink write technologies



Material Extrusion



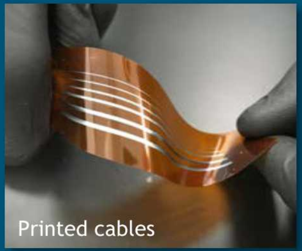
Material Jetting



Direct Ink Write

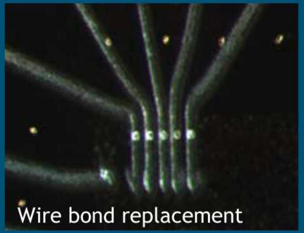
The direct ink write process directly supports fundamental materials research

- *Material agnostic*
- *Fully customizable platform*
- *Ease of instrumentation*
- *Maskless, digital printing*
- *Closed loop control*
- *Facile Prototyping for AM*
- *Rapid materials evaluation*



Printed cables

Printed Li $FePO_4$ battery

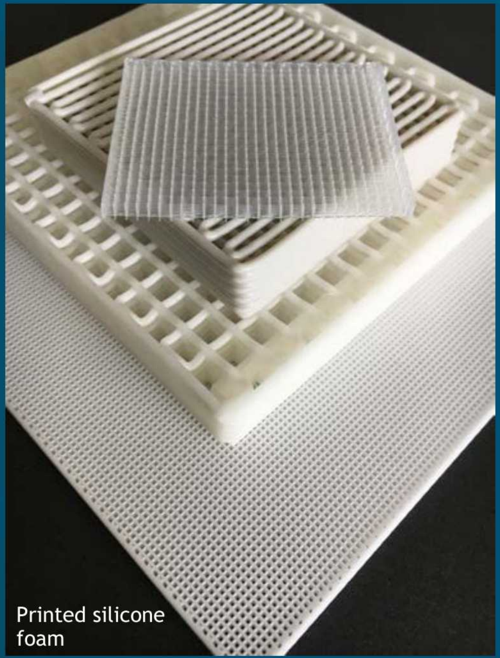


Wire bond replacement

Printed $CoFe_2O_4$

Printed Cu

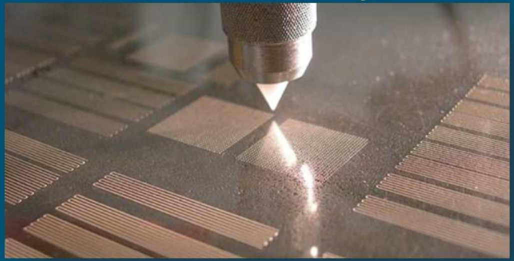
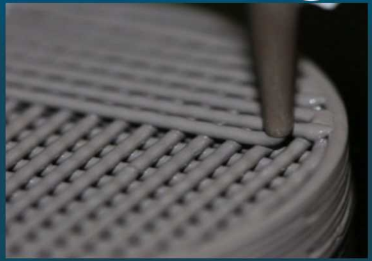
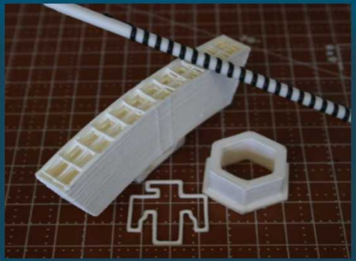
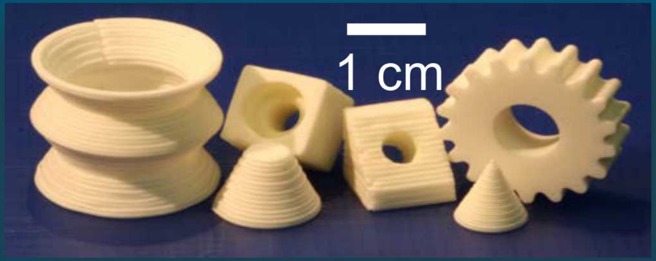
Printed Al_2O_3



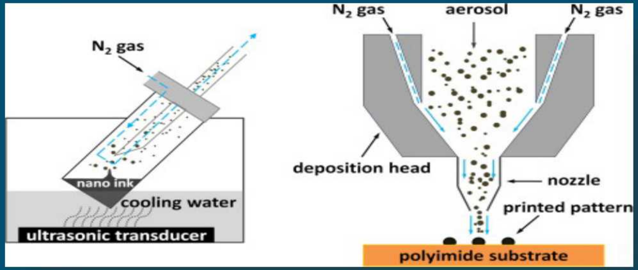
Printed silicone foam

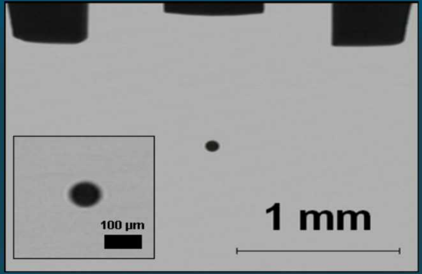
Direct write technologies enable access to materials not supported by conventional printing processes

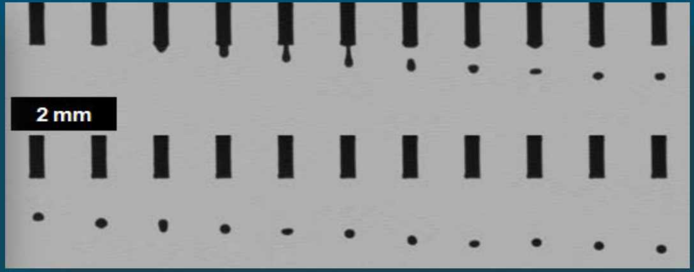
Direct Write by Extrusion Casting

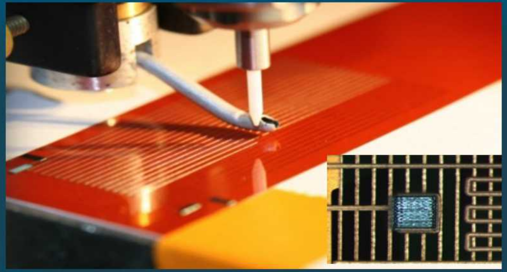





Direct Write by Aerosol & Ink Jet Deposition

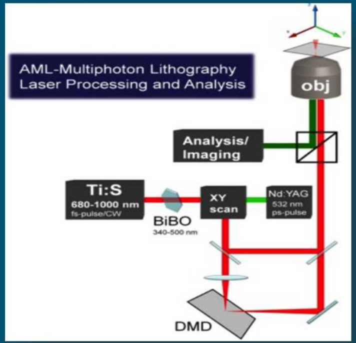


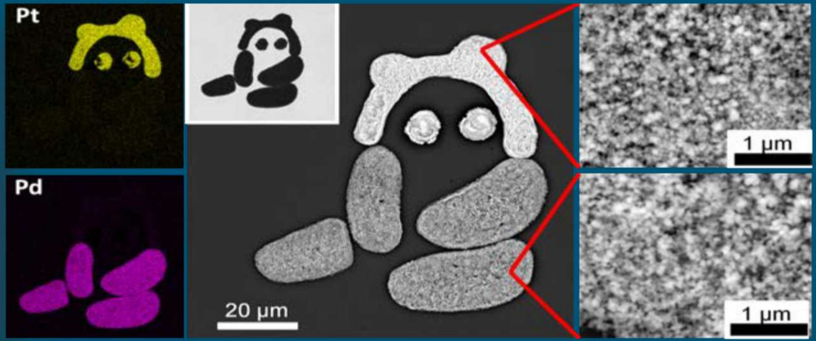


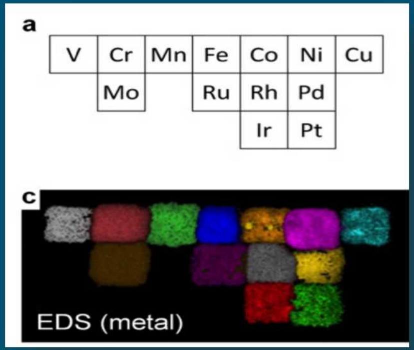


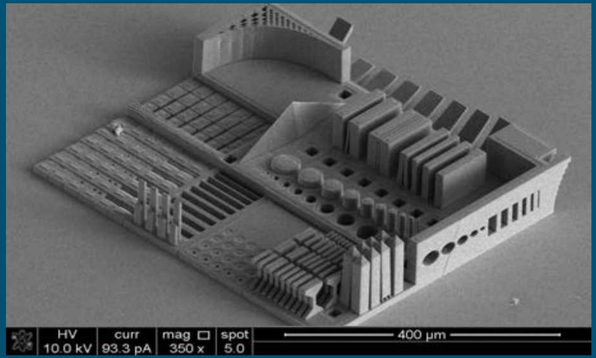


Direct Write by Laser Lithography





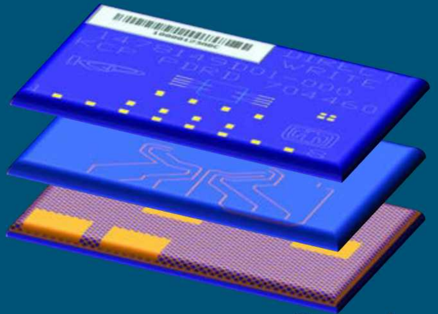
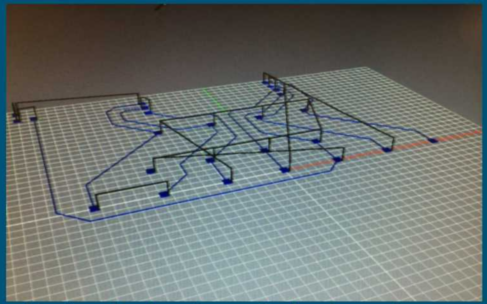
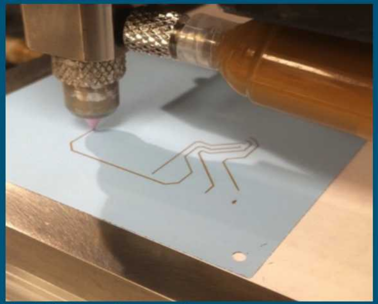




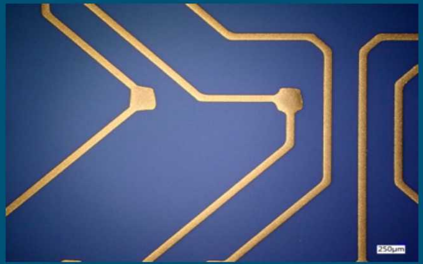
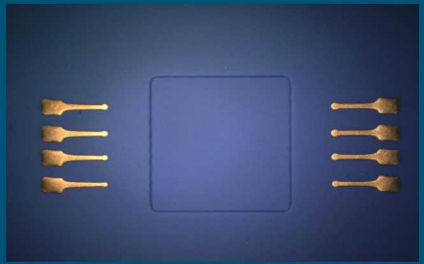
Direct write LTCC

Fabrication of multi-level, fully functional electronic circuits utilizing printed elements and ASICs

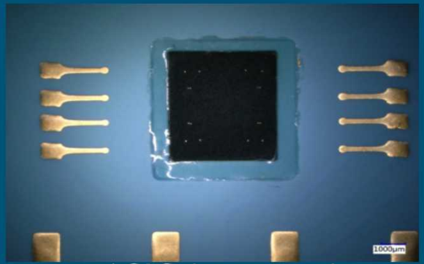
- Adaptation of qualified and accepted materials for use with additive manufacturing processes
- Demonstration of direct digital printing technique to complement conventional LTCC screen printing processes
- Ability to integrate high level ASIC functionality with direct write additive manufacturing

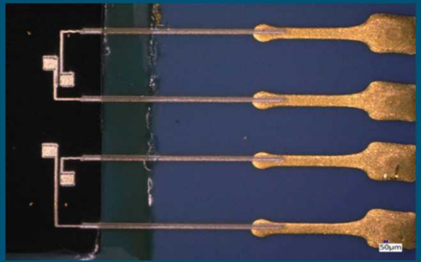
Complete digital design fabrication of LTCC circuits

High accuracy near fully- density metal interconnect

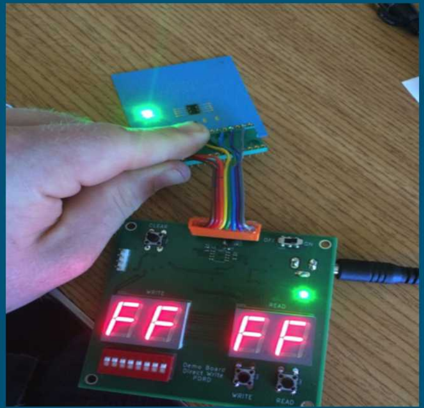


ASIC integration

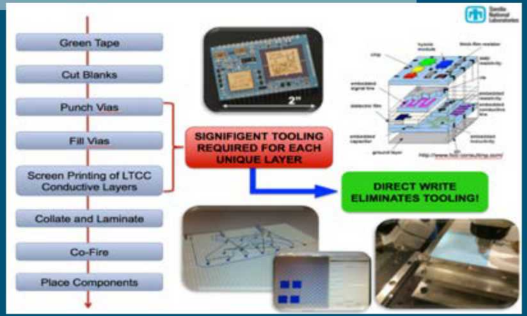


Wire bond replacement

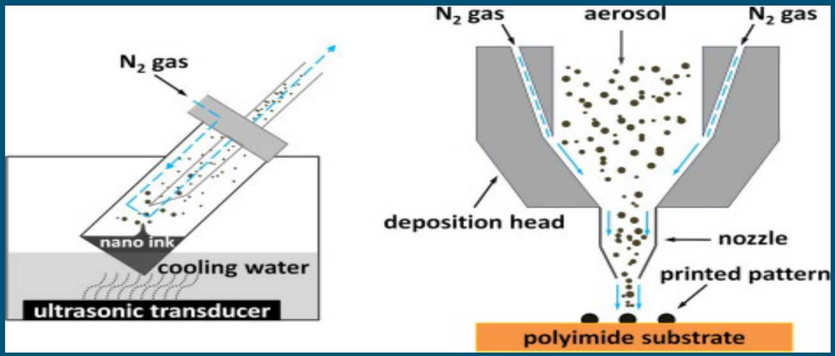
Completed four layer device

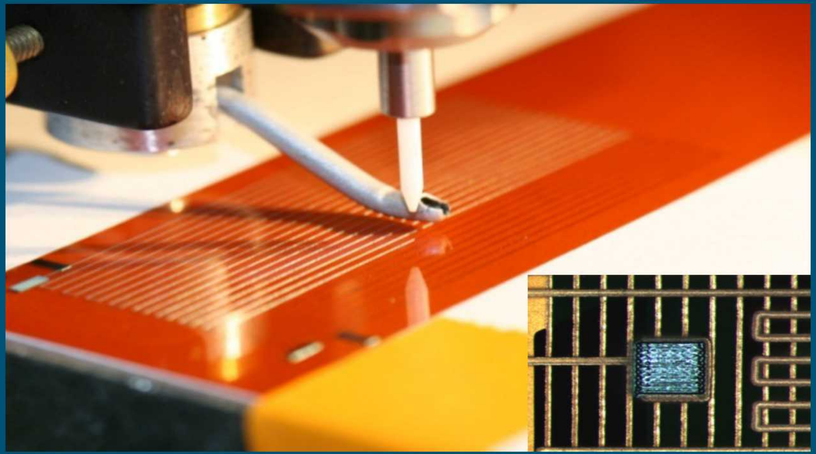


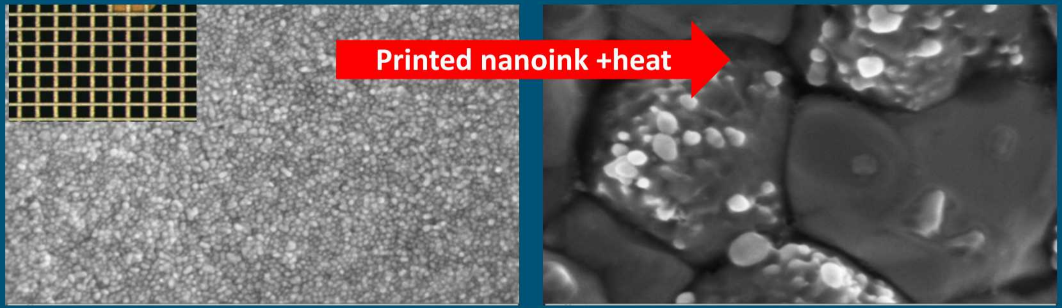
Data read-write functionality in fully printed LTCC component



Direct Write Printing by Aerosol Deposition

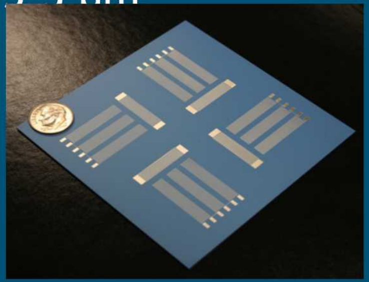






Aerosol Jet Printing Method

- 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