

Additive Manufacturing for Advanced Packaging and Electronics: Materials, Capabilities, and Integration Challenges

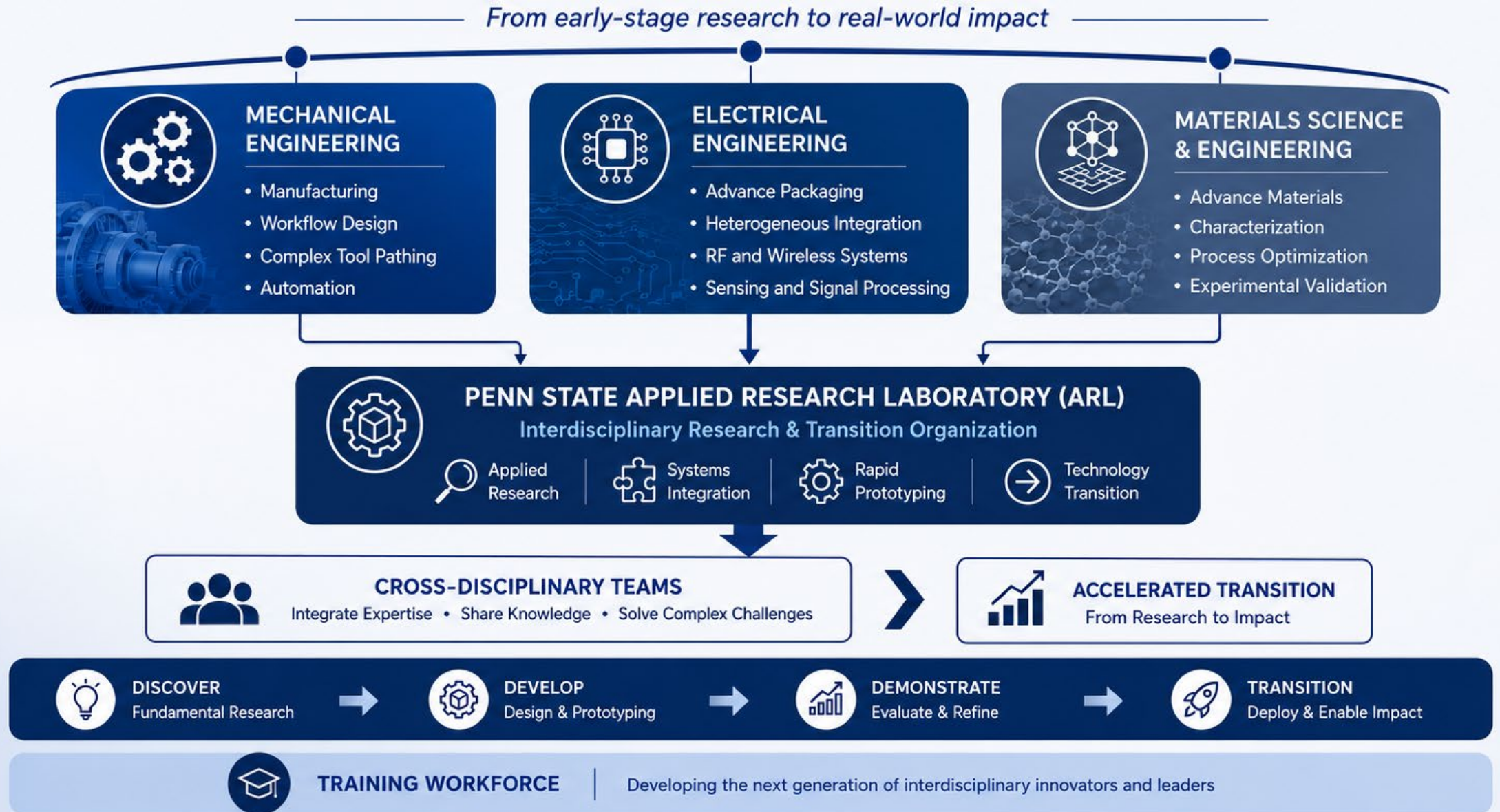
MATTHEW H. KROHN- PENN STATE UNIVERSITY

APPLIED RESEARCH LABORATORY

ELECTRONIC COMPONENTS AND TECHNOLOGY CONFERENCE

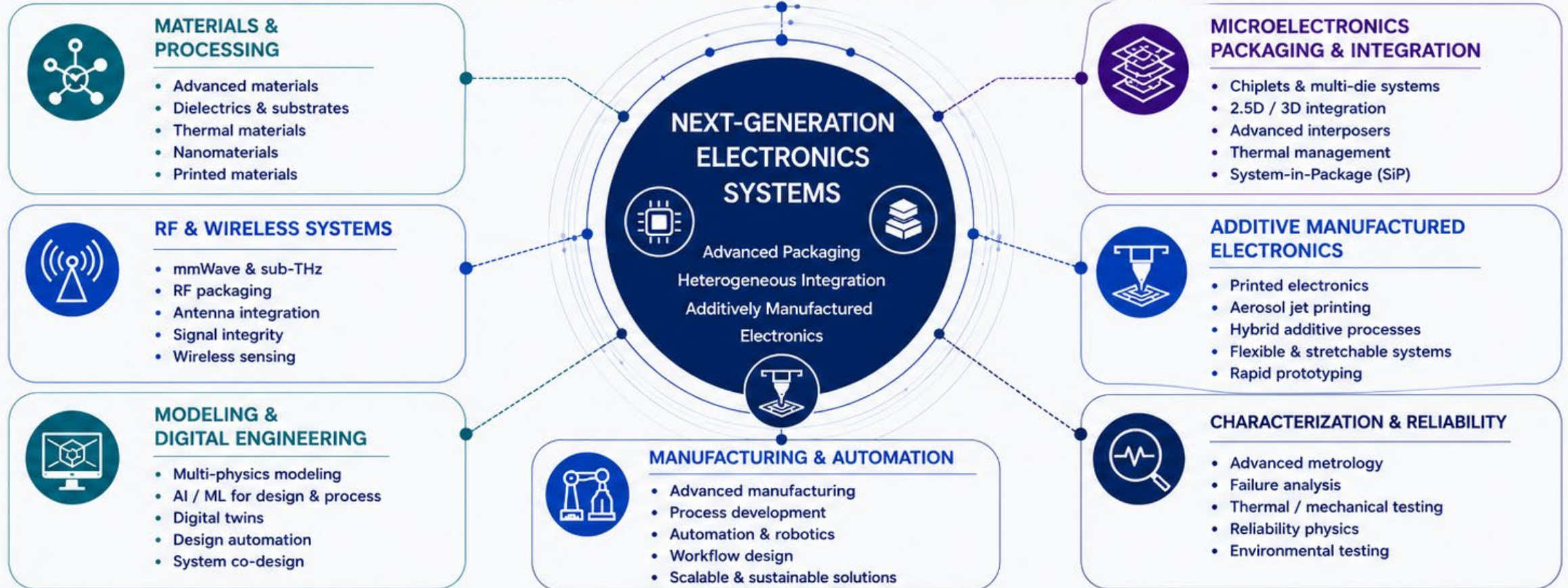
MAY 26-29, 2026 | ORLANDO, FLORIDA

Accelerating Technology Transition Through Cross Disciplinary Teams



Penn State Ecosystem for Advance Packaging and Heterogenous Integration

Cross-Disciplinary Research. Enabling Next-Generation Electronic Systems.



CROSS-DISCIPLINARY TEAMS



COLLEGE OF
ENGINEERING
ME, ECE, MSE
and more



MATERIALS
RESEARCH
INSTITUTE



NANOFABRICATION
& CHARACTERIZATION
FACILITIES



APPLIED RESEARCH
LABORATORY
(ARL)



INDUSTRY &
GLOBAL PARTNERS



GOVERNMENT &
ACADEMIC
COLLABORATORS



FUNDAMENTAL
DISCOVERY



INNOVATIVE
SOLUTIONS



PROTOTYPE &
INTEGRATE



REAL-WORLD
IMPACT

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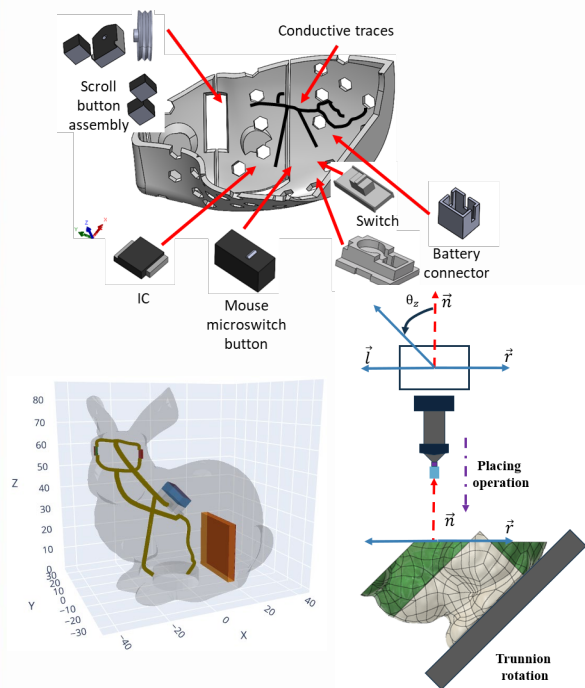


PROTOTYPE &
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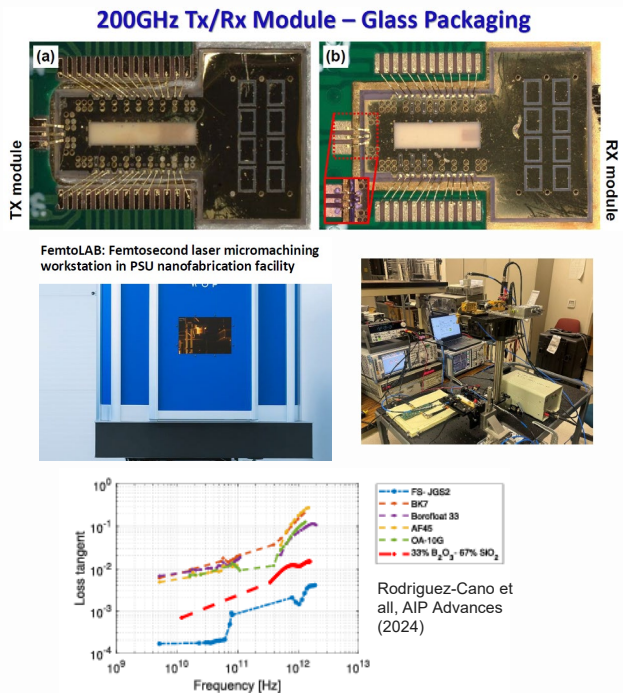
Examples of Current Programs at Penn State



HI-PEX: Hybrid AM Workflow for Conformal Electronic Manufacturing

Automate component placement, routing, toolpath generation, and multi-tool printing to rebuild complex electronic structures maximizing space utilization.

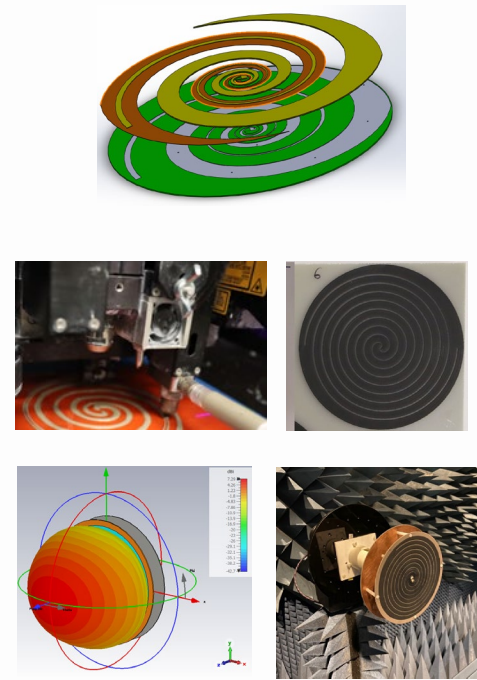
Key Benefit : Provides a strategic pathway for rapid adoption and production in high-mix/low-volume environments and access to bespoke systems



Low-Loss RF Glass: Engineered Substrates for High-Frequency Packaging

Develop silica-rich, low-modifier glass compositions that minimize ionic motion and dielectric loss for GHz–THz communications and sensing.

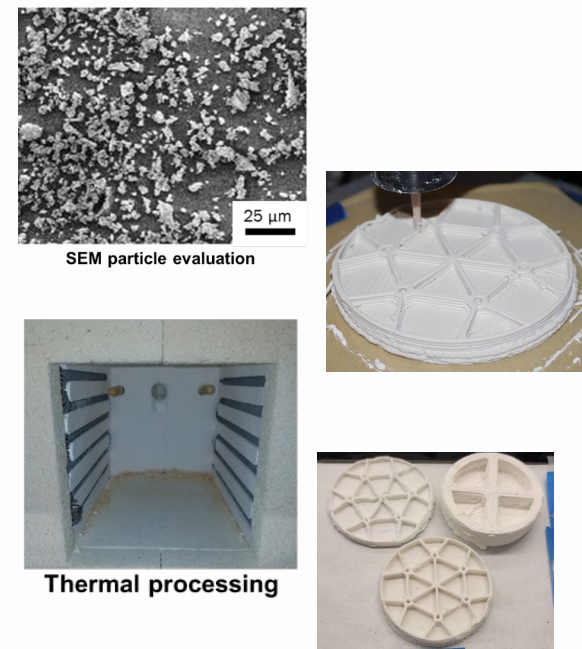
Key Benefit: Enables high-performance RF and advanced packaging through stable, low-loss, laser-processable glass substrates.



Antenna Prototyping: Rapid Additive Workflow for RF Design Evaluation

Simulation-driven additive manufacturing to quickly prototype and test antenna designs, materials, and processes.

Key Benefit: Dramatically shortens development cycles through fast, iterative build-and-measure workflows.

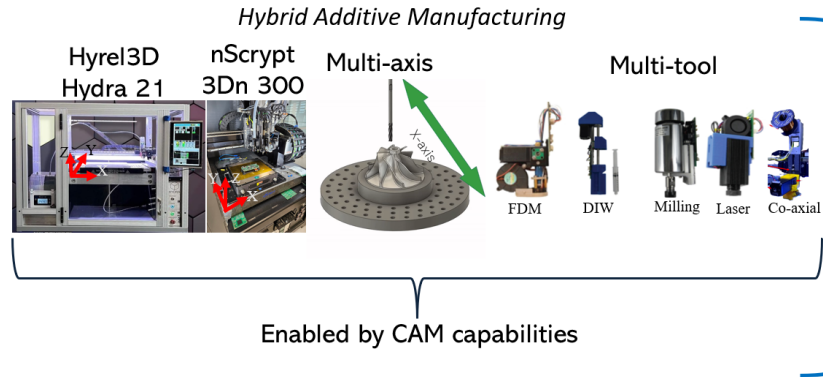


AM of Ceramics and Functional Composites

Advances additive manufacturing of high-performance ceramic and composite materials development of optimized and engineered inks.

Key Benefit: Enables rapid, application-specific development of advanced material systems with tailored thermal, magnetic, and structural performance.

HI-PEX: Hybrid AM Workflow for Conformal Electronic Manufacturing



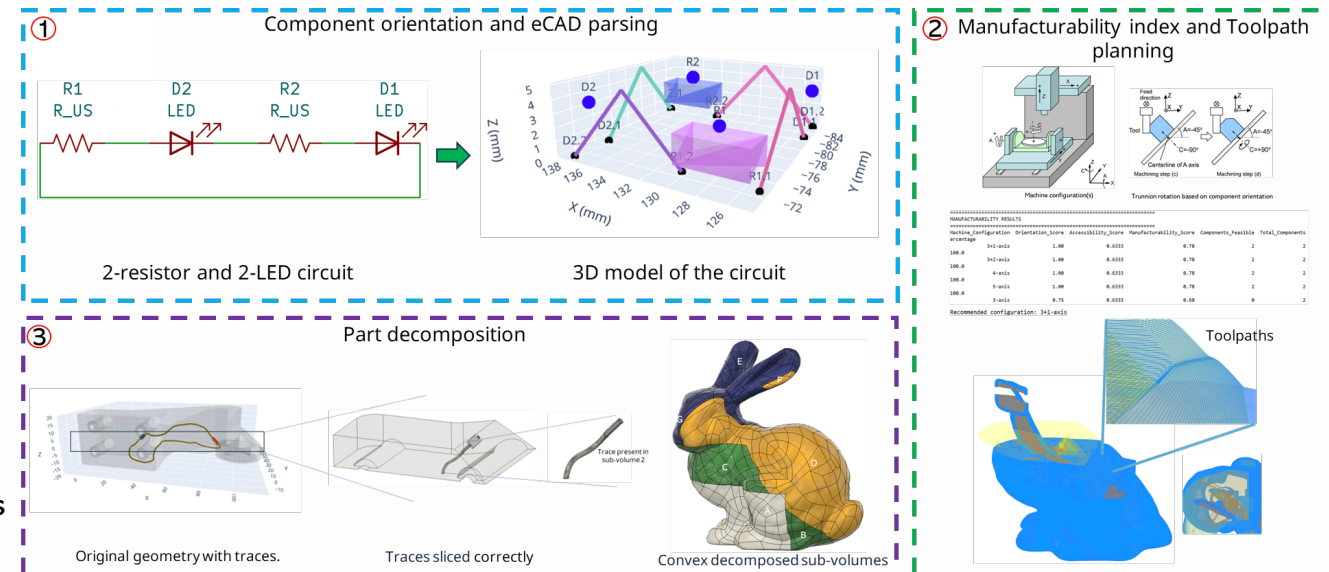
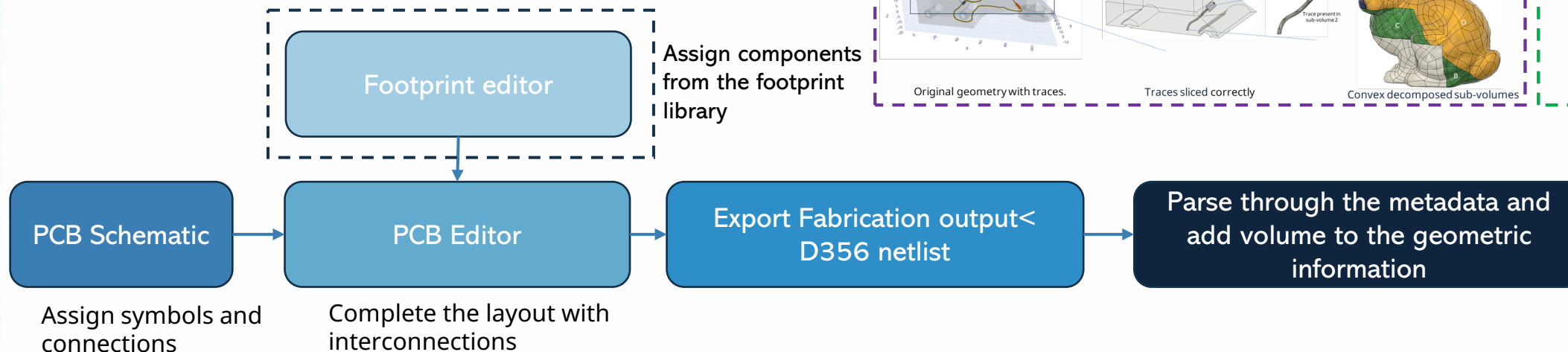
*H*eterogeneous
*I*ntegration and
*P*ackaging of
*E*lectronic systems in
X-multi-axis tools and processes

Technical Challenges:

- Printing multiple materials within the same layer and curvilinear layers is not just a complex scheduling challenge but also introduces tool-part collisions
- No CAD modeling software exists that could automatically embed circuits inside a 3D volume from a schematic

Goal:

- Automating the eCAD process from PCB schematic to CAD generation to include this netlist inside any 3D geometry.
- To extract the metadata from D356 to convert the netlists and geometric information into a 3D geometry.



Low-Loss RF Glass: Engineered Substrates for High-Frequency Packaging

Why Glass → Superior Electrical Properties

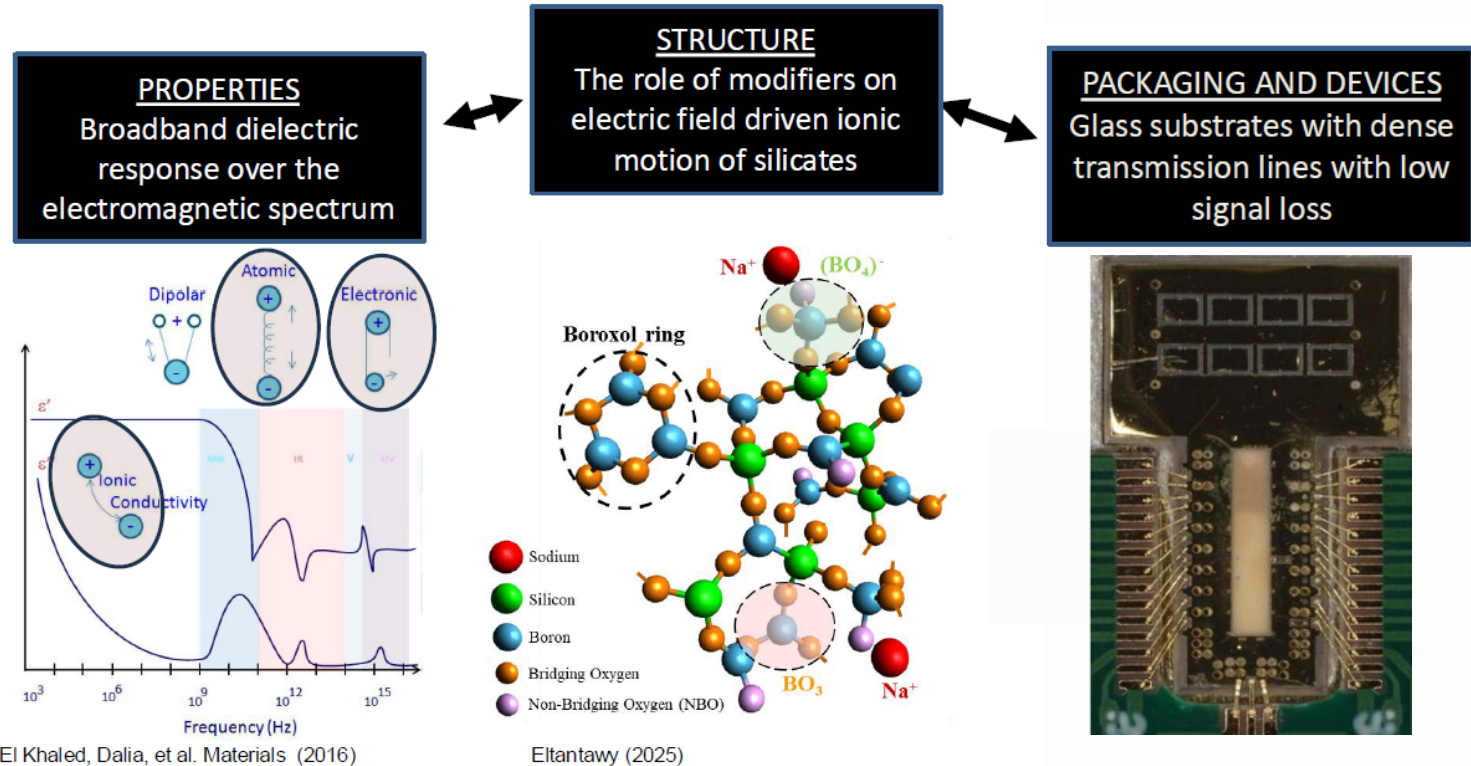
- Low dielectric constant reduces signal loss and improves high-frequency performance
- Excellent electrical insulation minimizes crosstalk between densely packed components

Challenge

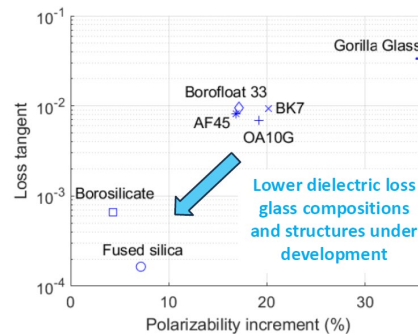
- Current glasses are not optimized for dielectric loss and not ideal for high frequencies applications

Focus

- Develop a low loss glass for applications in the GHz-THz range to be processed below 1650 C
- Evaluate laser processing impact on chemical, structural, and mechanical and dielectric properties



Design Compositions

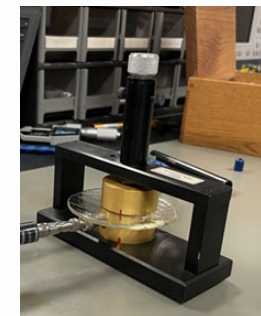


Develop Process



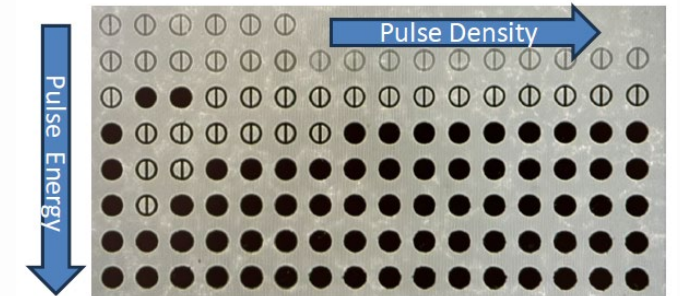
Credit: Christina Hunter

Evaluate Performance



Credit: Michael Marakovits

100 μ m diameter vias in high dielectric loss commercial glass



Credit: Wanlin Zhu

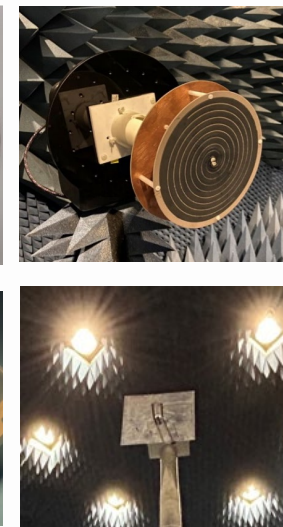
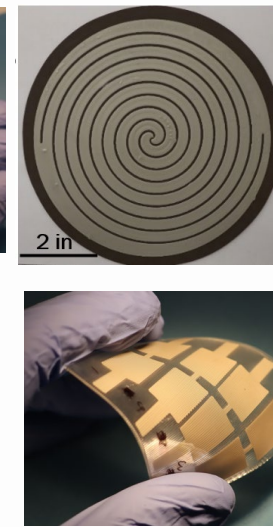
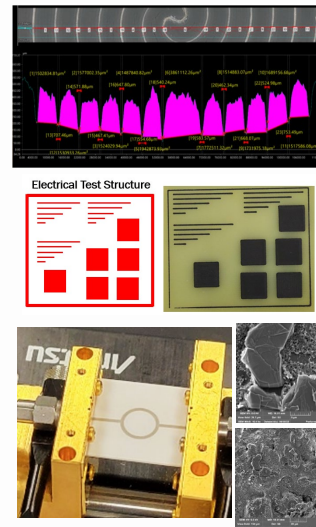
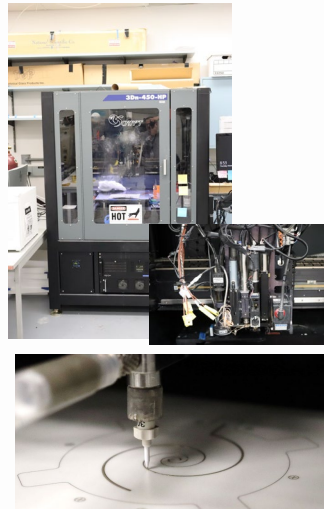
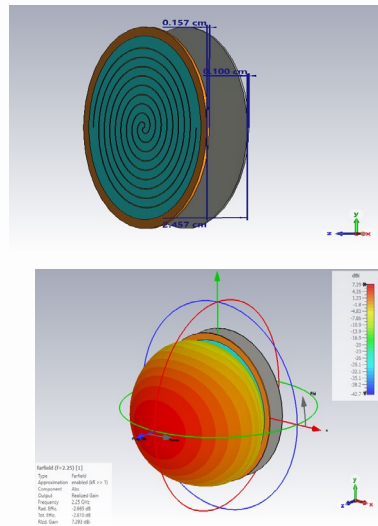
Antenna Prototyping: Rapid Additive Workflow for RF Design Evaluation

Motivation → Implement process to design and evaluate antenna designs

- *Evaluate design, processes and materials in parallel*
- *Consider integration and field performance early in process*

Enabling technology

- Design toolchain to move from model to print
- Access to various processes for prototype build
- Ability to quickly test RF performance

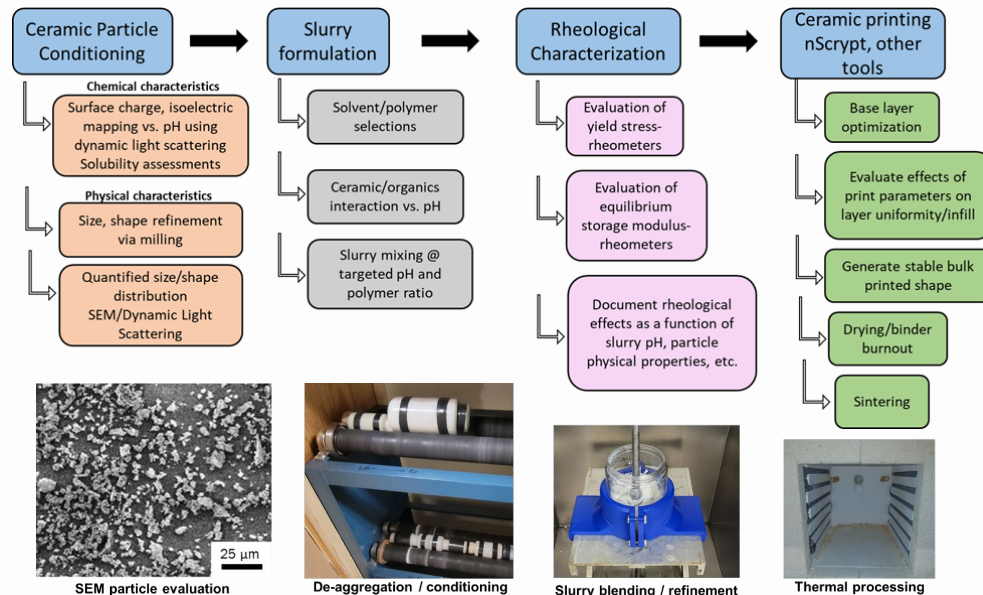


AM of Ceramics and Functional Composites

Approach: Leverage diversified materials processing toolset to modernize and develop advanced manufacturing techniques providing broad-reach, innovative technical solutions

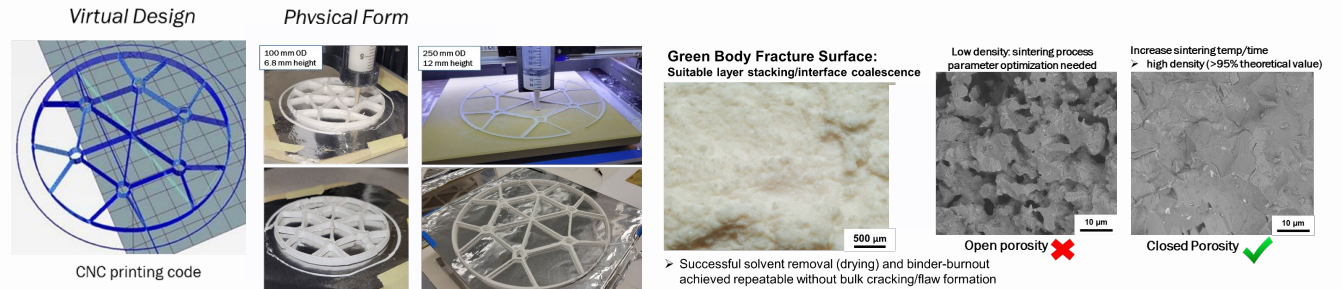
- **Novel Materials and Inks:** Development of processing routes and inks for functional ceramic materials.
- **Multiple Materials:** Printing of meta-materials for targeted functionality and/or sensing.
- **Integrate structural and functional components :** Leverage multiple additive and subtractive process to define route to functional devices and sensors.

Slurry Development

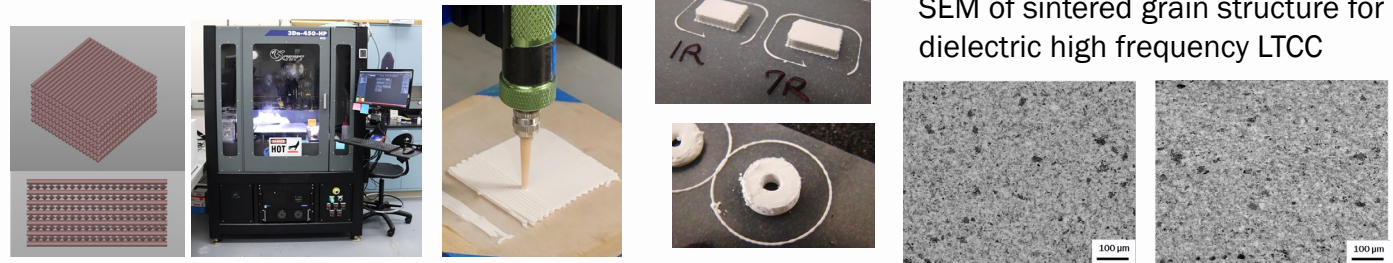


Example Programs

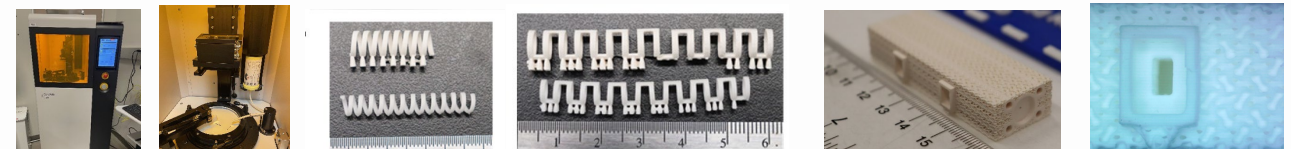
Direct writing of low CTE ceramics structures



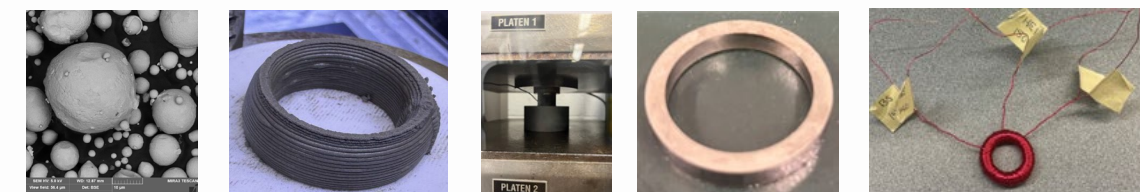
LTCC and NCOC Green Body Printing



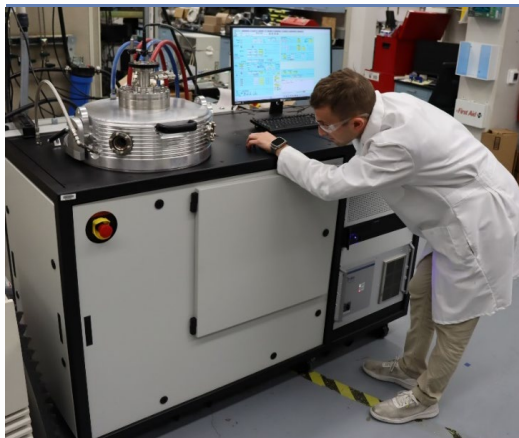
Additively manufactured high frequency RF ceramics components



Printing and low temp densification of soft magnetic composites

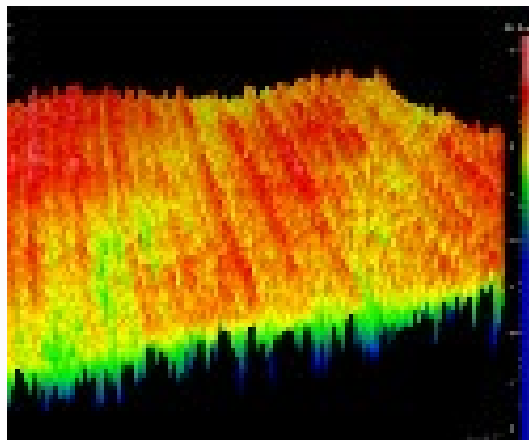


Challenges to address



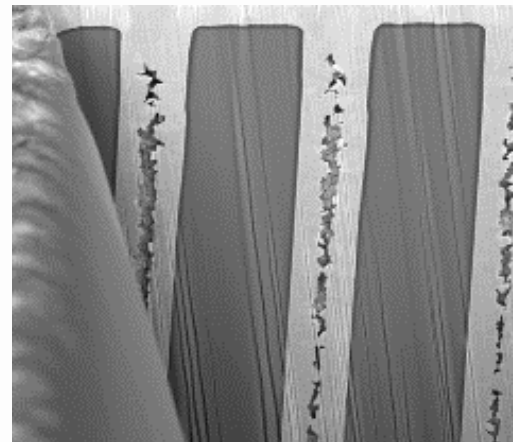
Materials

- Greater consistency in material properties and post-processing outcomes is essential for predictable electrical and mechanical performance.
- Reliable materials data will help qualify AME for demanding applications and build confidence in long-term stability..



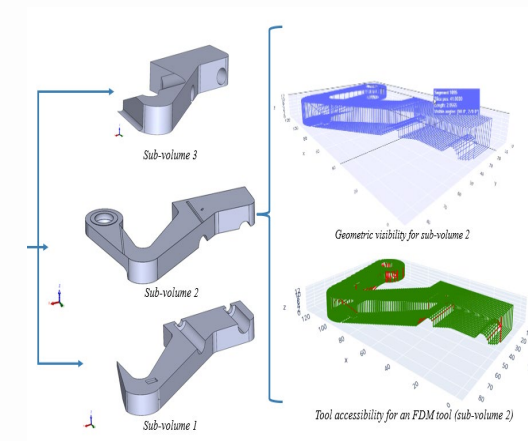
Feature Size and Surface Roughness

- Current feature limits and surface roughness constrain high-frequency and high-density performance.
- Reducing roughness and tightening dimensional control will directly improve conductor loss and signal integrity.



Multi-Material Integration & Reliability

- Interfaces between dissimilar materials must withstand thermal cycling, moisture exposure, and mechanical stress.
- Demonstrating robust bonding and repeatable reliability is critical for adoption in mission-critical systems.



Digital Design Tool and Workflows

- Today's tools lack seamless support for embedding circuits and routing within complex 3D geometries.
- Enhanced automation and verification workflows are needed to accurately predict performance in multi-material, fully 3D designs.

PATH TO Success:



Targeted Applications

Focused on high-impact challenges where AME offers clear performance or integration advantages.



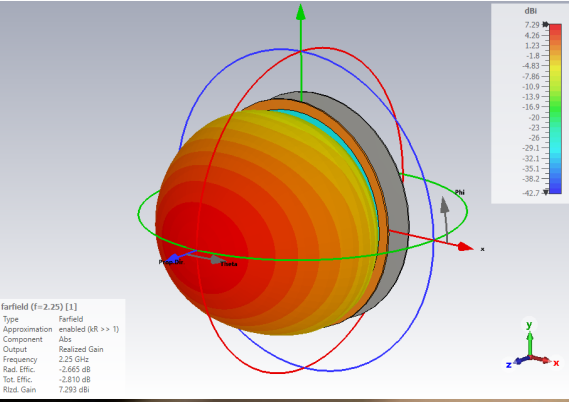
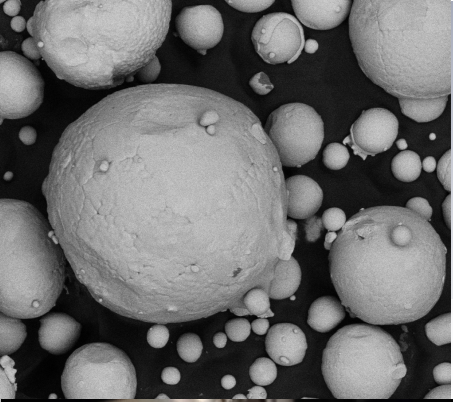
Maximize Value

Identify opportunities where AME delivers unique benefits rather than matching existing manufacturing methods..



Cross disciplinary collaboration

Leverage expertise across materials, design, RF, thermal, and manufacturing to accelerate innovation.



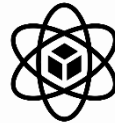
Looking Forwarded

Where Additive Manufacturing Can
Make an Impact



Advanced design tools

- Access to multiphysics-aware CAD and eCAD tools accelerates design cycles.
- Process-aware workflows support faster iterate-test-learn development.



Materials and system reliability data

- Increasing real-world cases and test data will build confidence in AME performance.
- Reliable materials and system-level results will help validate durability, stability, and long-term operation.



Cross Functional Teams

- Tight integration across materials, RF, thermal, reliability, and manufacturing enables rapid coordinated solutions..



Rapid Prototyping

- Agile prototyping accelerates design evaluation and reduces early-stage risk.
- Fast pivoting between concepts, materials, and architectures keeps development aligned with mission needs.



AM to target challenges

- Non-planar, embedded, and multi-material structures expand what is possible in advanced packaging.
- AM supports chipllets, 2.5D/3D architectures, improved thermal routing, and conformal RF features.



Future Needs

- Standards, metrology, and PDKs will improve repeatability and reliability.
- Expanded materials libraries and integrated co-design tools will enable electrical, mechanical, thermal, and RF optimization.

Collaborators



PennState
College of Engineering

HAROLD AND INGE MARCUS
DEPARTMENT OF INDUSTRIAL AND
MANUFACTURING ENGINEERING

**AEROSPACE
ENGINEERING**

**ELECTRICAL ENGINEERING
AND COMPUTER SCIENCE**



PennState
College of Earth and Mineral Sciences

Department of Materials
Science and Engineering

Dr. Guha Manogharan

Dr. Sven Bilén

Dr. Madhavan Swaminathan

Dr. John Mauro

Dr. Micheal Yukish

Dr. Douglas Werner

Dr. Michael Lanagan

Dr. Callie Zawaski

Dr. Daniel Lopez

Dr. Joshua Robinson

Dr. Luke Lyle

Mr. Joshua Fox

Mr. Robert Lavelle

Mr. Daniel Erdely

Collaborations Driven through various centers, institutions and labs.



PennState
Center for Innovative Materials Processing
Through Direct Digital Deposition

CHIMES

Center for Heterogeneous Integration
of Micro Electronic Systems



PennState
Materials Research
Institute

nanofab
The Nanofabrication Laboratory



POWERED BY
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silicon carbide
innovation alliance



PennState
Applied Research Laboratory



PennState
Materials Research
Institute

MCL

MATERIALS
CHARACTERIZATION LAB



The S.H.A.P.E. Lab

Systems for Hybrid-Additive Process Engineering lab

CEDE

Penn State Center of
Excellence in Directed Energy



CGR

Center for Glass Research

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- +
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- +
- Thank you.
- +
- mhk119@psu.edu
- +
- (814)865-8134