

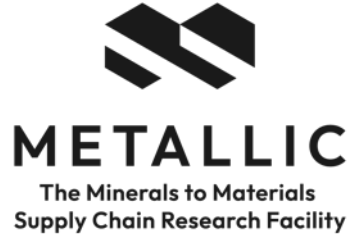
METALLIC: The Minerals to Materials Supply Chain Research Facility



Center 4: Alloy Design and Advanced Manufacturing



Meet the Team: METALLIC Center 4 – ADAM*



Scott McCall
Center 4 Lead



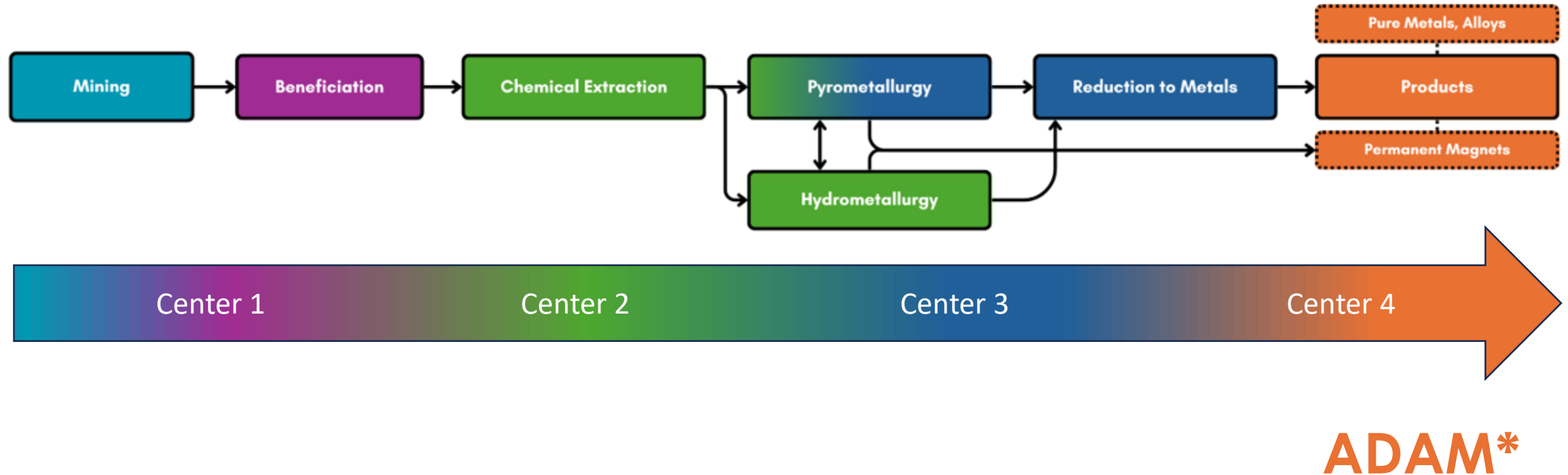
Glenn Grant
Center 4 Co-Lead



Jun Cui
Center 4 Co-Lead

How Center 4 (ADAM*) fits into the METALLIC structure

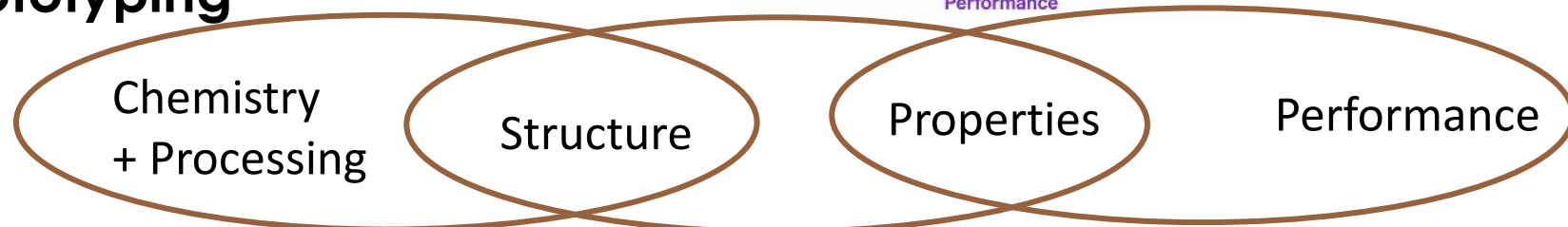
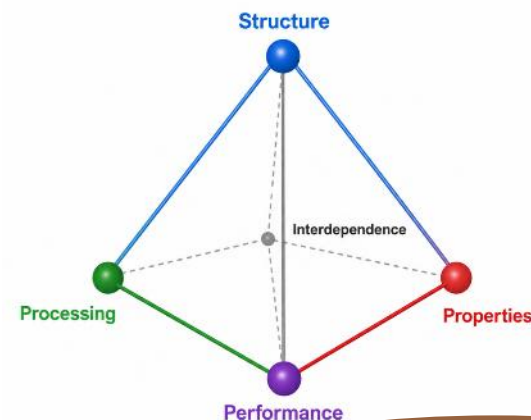
Building collaborations and workflow across teams



Advancing refined materials to components

Flagship Activities:

1. Solid Phase Processing
2. Advanced Alloy Development
3. Semiconductor Testbed
4. Advanced Topology Prototyping



Resource for Industry:

- **Accelerate Bench to Pilot Scale Evaluations:** Evaluate new technologies at scales relevant to industry (TRL 5-6)
- **Commoditize Advanced Manufacturing:** Map processes onto intrinsic properties rather than extrinsic machine parameters
- **Reduce Materials Intensity:** Develop tools to minimize the critical materials required

Flagship #1: Solid Phase Processing

Extreme Metallurgy: Improved materials properties by targeting microstructures (<1 kg – 1 ton)

Representative Existing capabilities:

- Advanced Magnet Facility-(pilot production, validation, data-sheets)
- Thermal Processing: VIM, VAR/ESR, Arc furnaces <200 kg
- Thermo-mechanical processing: rolling mills, 500-ton press forge, annealing furnaces
- ShAPE*, extrusion

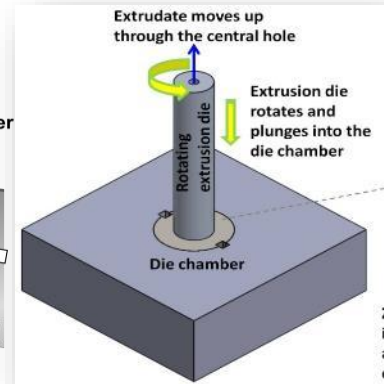
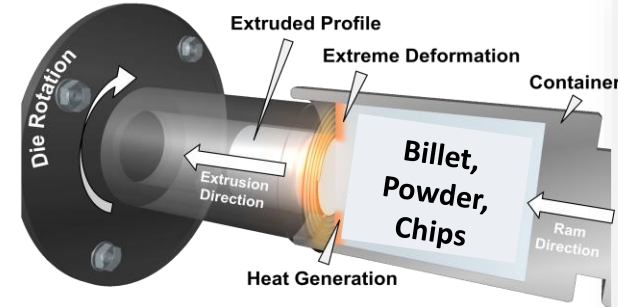
Representative New Capabilities

- **ShaPE 4:** Controlled atmosphere, >3 kN-m Torque
- **Magnet hot-rolling**
- **Expanded Processing:** 1500-ton forge, 900-ton extrusion press, e-beam furnaces

Reshored domestic production is not going to be based on technology exported decades ago



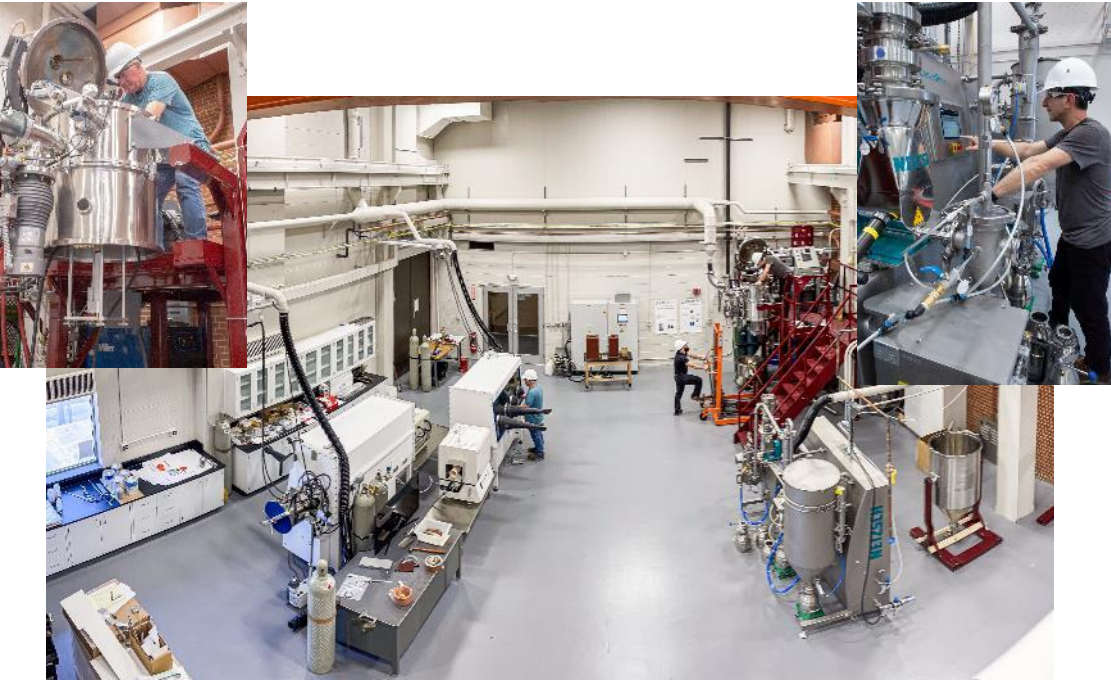
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Advanced Processing Capabilities



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Established by CMI and available to METALLIC users

The Advanced Magnet Facility enables production and validation of magnets at the pre-pilot scale (kg)



AASC
Advanced Alloy
Signature Center

Established by DOE and available to METALLIC users

A variety of thermomechanical processing capabilities are available such as those at AASC

Flagship #2: Advanced Alloy Processing

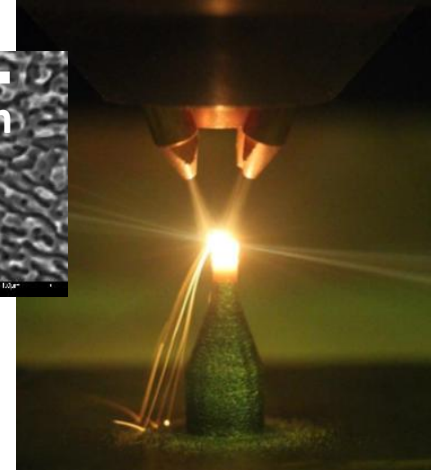
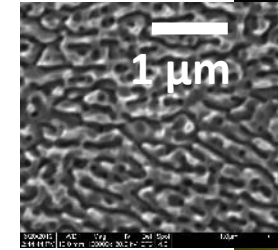


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Quantifying material parameters to scale AM, enabling tool independent production

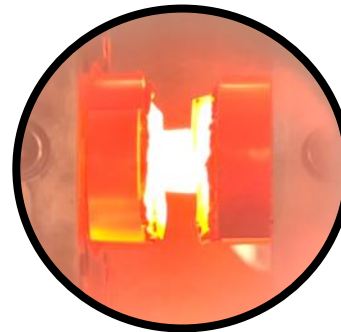
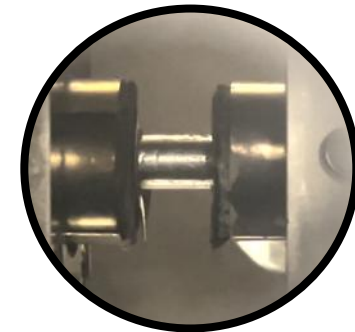
Existing Capabilities

- Thermomechanical simulation (mechanical properties to $\sim 3,000$ °C)
- Custom powder production (evaluation scale: 0.5-50 kg batches)
- Additive manufacturing machines such as DED and LPBF
- Electron microscopy (SEM, TEM, microprobe, etc.)
- High temp XRD (>1400 °C)
- Alloy design software with world leading CMM databases



New Capabilities coming on-line

- High temperature characterization >2000 °C (emissivity, thermal properties, electrical properties)
- HIP (2200 C, 45 ksi, 8" w x 12" hot zone) multiple atmospheres

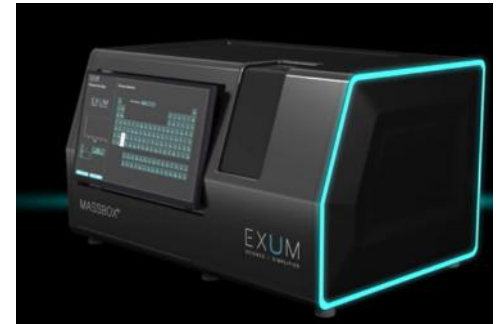
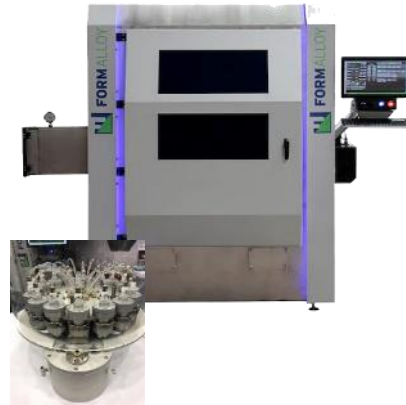
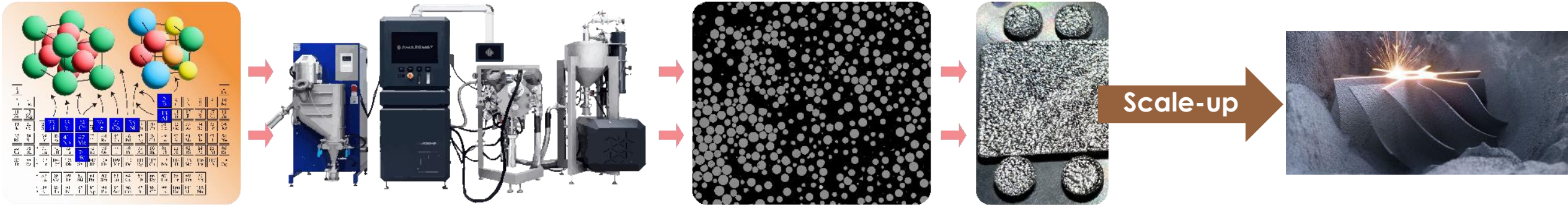


Custom alloys require custom processing

Evolving advanced manufacturing processes require standardization



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Multi-lab Existing Capabilities

(LA-LI)-ICP-MS

Advanced
Characterization

How parameters change with scale is a complex multivariate problem

Flagship #3: Autonomous Semiconductor Processing Suite



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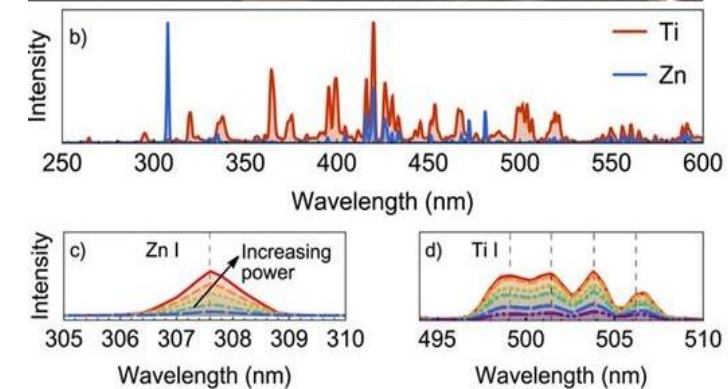
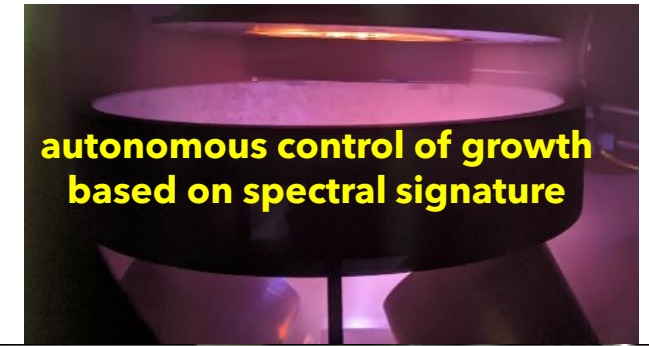
Accelerating “lab-to-fab” technologies for advanced semiconductors

Existing Capabilities

- Autonomous sputtering systems with *in-situ* tools (4” wafers)
- Integration of autonomous experimentation, instrumentation, and AI-driven decision-making

New Capabilities coming on-line

- **Processing Scale:** 6” wafers with high-throughput processes
- Autonomous control of complex multi-variate growth phase diagram for semiconductors including UWBG materials
- Real-time, *in-situ* spectroscopy enables physics-based control of parameters to obtain desired properties



***In situ* spectroscopy during sputter deposition of Zn-Ti-N semiconductors**

Reshoring manufacturing requires deploying advanced processes that can produce higher-quality products using critical materials more effectively.

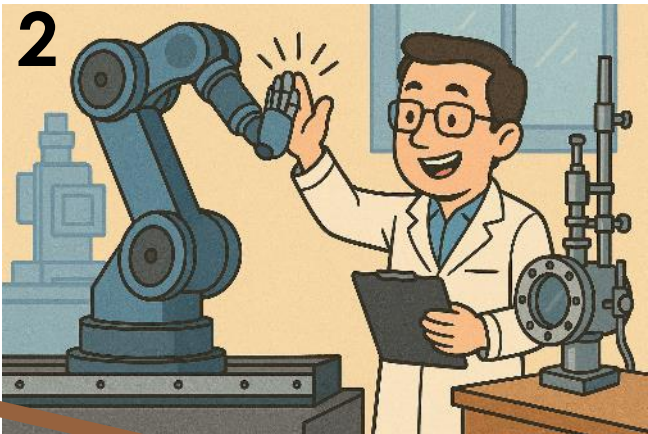
Autonomous Semiconductor Processing Suite Timeline



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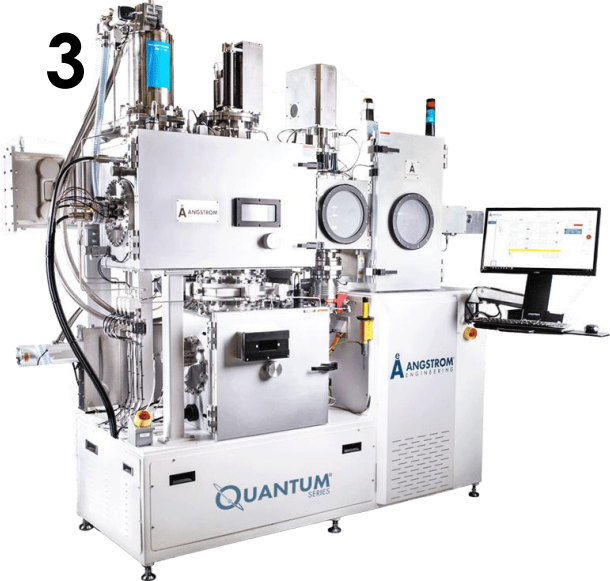
2. Robotic characterization suite enabling on-the-fly properties feedback



4. Integrated system with autonomous control based on process variables and properties, alongside external automated characterization

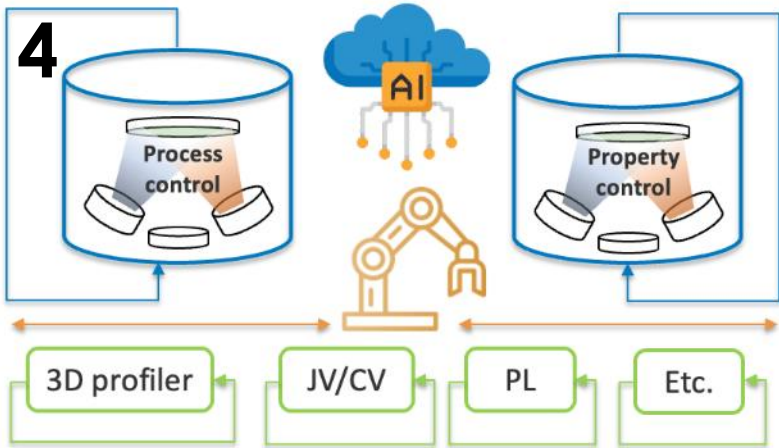


1. Existing tool with process-monitor-based *autonomous* control but manual sample transfer



3. Installation of new automated growth tool with measured-properties-based autonomous control

Enduring Impact
Rapid development of reduced CM semiconductor materials



Flagship #4: Advanced Topology Prototyping



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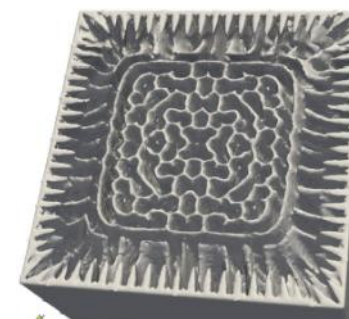
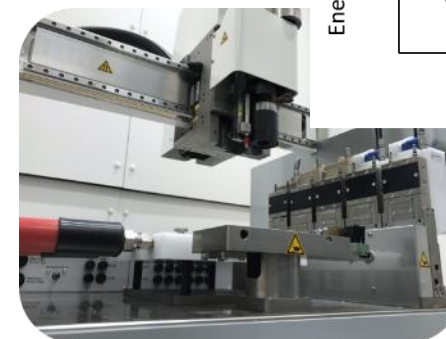
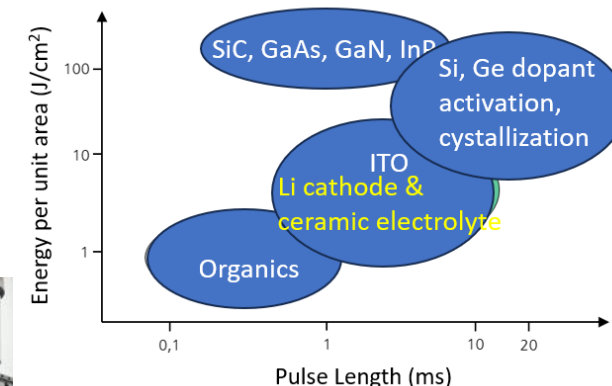
Better living through geometry: Design and development of complex topologies and AM enabled architecture prototyping

Existing Capabilities:

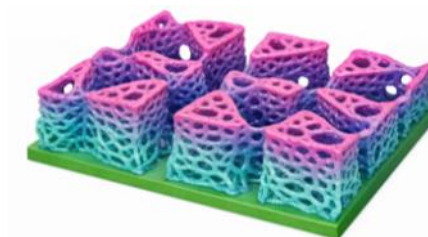
- Pilot-Scale R2R Coating System
- Rapid membrane prototyping and scaling for CMM separations.
- Photonic annealing: up to **60 J/cm² per pulse**
- Design optimization tools (software)

New Capabilities coming on-line

- In-line metrology and AI-enabled smart manufacturing for enhanced yield and CMM efficiency
- Film compatible thermal process development for device integration



Electrochemical Devices



Topological Structures

Advanced processing for device integration



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Integrating in-line metrology to enable real-time quality control

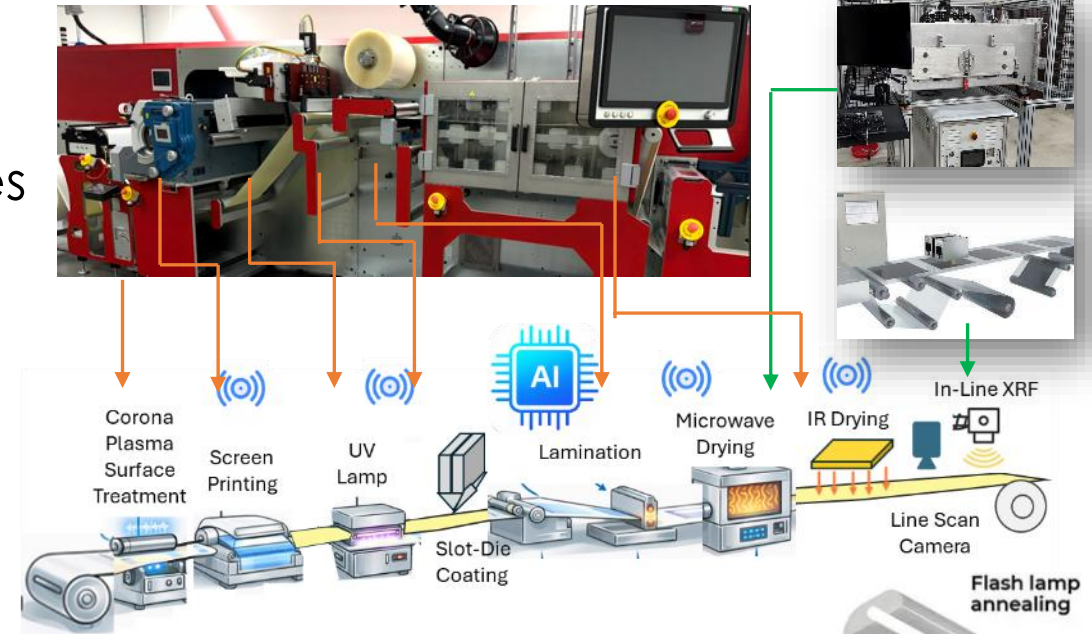
- In-line line scan camera, pyrometer sensors, microwave unit, and XRF
- Photonic annealing: high energy density, ms pulses to minimize thermal diffusion

Enabled capabilities:

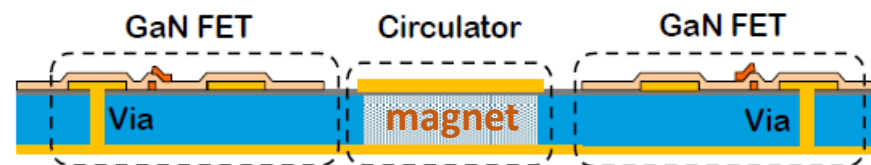
- Device development for multi-material components
- Design of components with reduced critical materials intensity



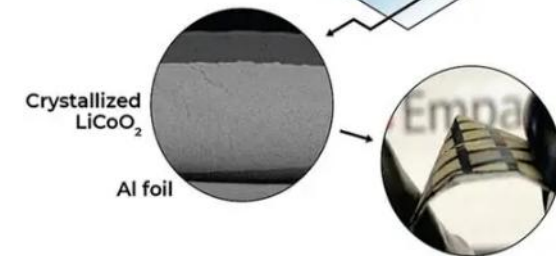
Pilot-Scale R2R Coating System



Circulator integrated with GaN-on-SiC



Thin film battery



ADAM* Flagships offer broad support to industry:



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Solid Phase Processing:

- Magnet formulation, feedstock evaluation, and data-sheet validation
- Processing of advanced alloys
- Development of new alloy processes

Scale: 1-1000 kg

Advanced Alloy Processing

- Diagnostics for tool agnostic advanced manufacturing
- Alloy evaluation under and for extreme conditions
- Advanced Alloy Development

Scale: 1-100 kg, 2000+ °C

Autonomous Semiconductor Processing

- Thin film autonomous processing tools
- Process-monitor-based autonomous control
- Robotic characterization suite

Scale: 4-6" wafers

Advanced Topology Prototyping

- Rapid membrane prototyping and scaling for CMM separations.
- AI-enabled autonomous coating
- Development of complex topologies and AM enabled architecture prototyping

Scale: 40-80 m/min; 0.3 m web width

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