Advanced Manufacturing Overview: Idaho National Laboratory

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CAES Roundtable

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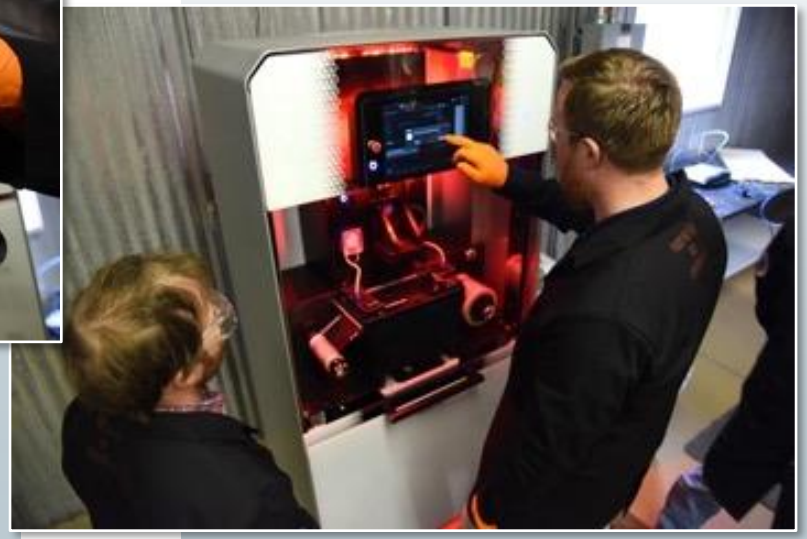
Enable and accelerate the nation's access to vital energy materials & systems for extreme environments

U.S. industrial competitiveness for harsh materials in energy production systems

Secure design and manufacturing processes for nuclear, energy, space, and defense

New additive and field assisted sintering techniques for the manufacturing of high-fidelity designs that can be industrially scaled



Process Discovery → Refinement, Qualification and Intensification → Deployment

INL advanced materials, instrumentation, and energy technologies for extreme environments





Advanced Materials and Manufacturing for Extreme Environments

- Process discovery & development for nuclear, energy defense and space systems components
- Secure digital design and manufacturing
- Intensification and scale-up

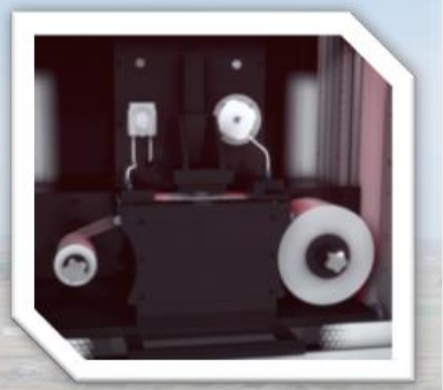
Advanced Manufacturing at the INL's Research & Education Campus

Spark Plasma Sintering & Flash Sintering

Irradiation Capsule Fabrication

Additive Manufacturing LENS, FDM, Plasma Jet, binder Jet

Roll to Roll



Electronics & Instrumentation

Metals Polymers & e-waste recycle

Laser Welding & Annealing

Process Science, M&S

Coatings & Surface Control e.g. Plasma Spray, CVD, PVD

Hot Press & Isostatic Press

Advanced Manufacturing Capabilities Development at MFC-AFF

Spark Plasma Sintering & Flash Sintering

Irradiation Science Driven Specimen Fabrication

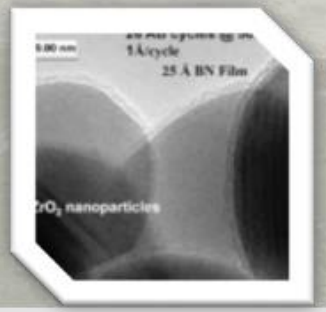
Additive Manufacturing
LENS, SLA & DLP

Feedstock Control & Single Crystal Growth

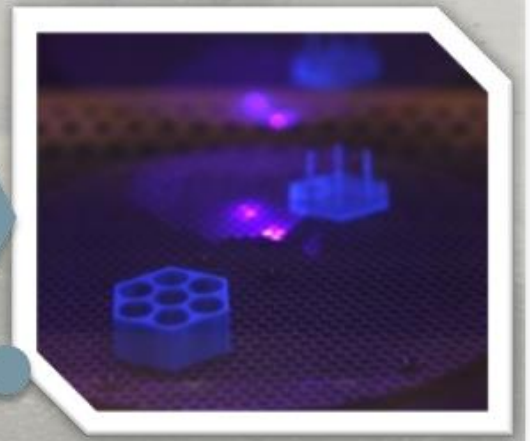
Advanced coatings
ALD & CVD

Laser Welding & Annealing

Hot Isostatic Presses & Dry Bag Press

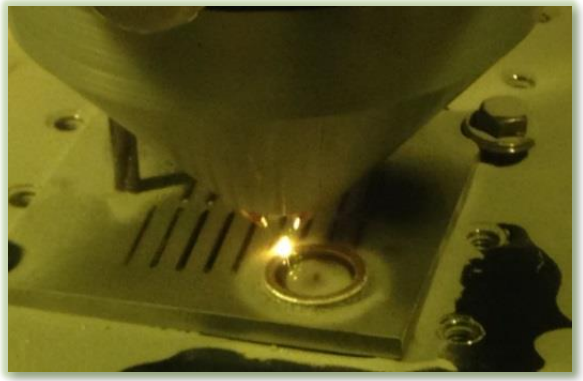


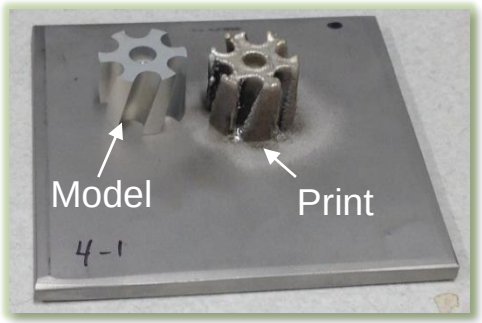
Process Flow sheet Development



Direct Energy Deposition

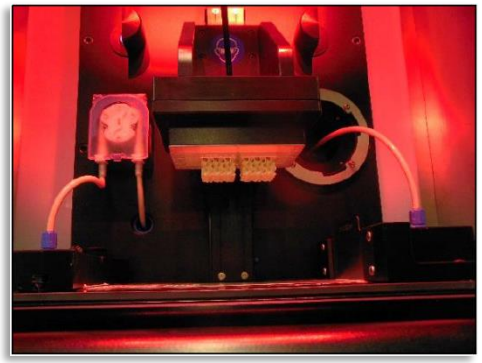
- Two Optomec systems (MR-7 and MTS1 LENS)
  - 1kW laser
  - ~50x30x50 cm working volume
  - Controlled atmosphere
  - Multiple powder hoppers
- Complex geometries, multiple materials

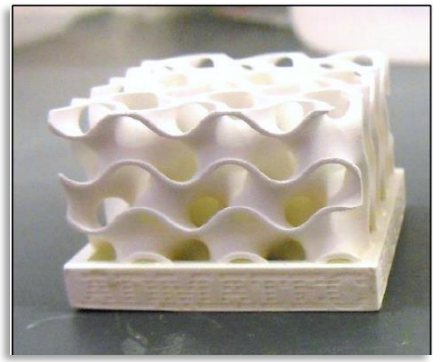


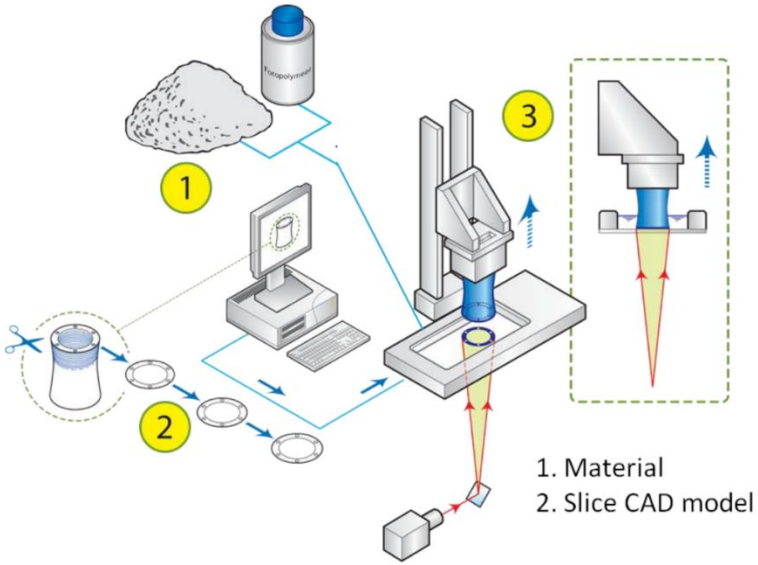


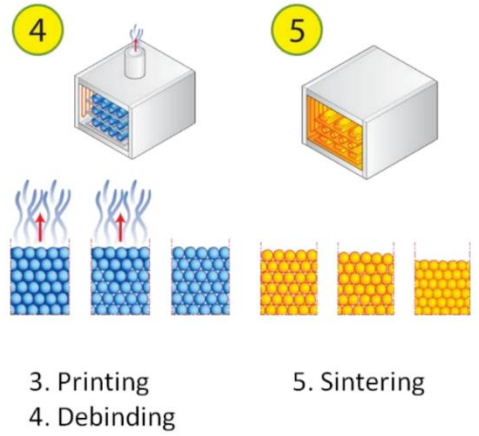
Digital Light Processing (DLP)

- Two Admaflex 130 ceramic DLP system
  - Build Size – 96 x 54 x 120 mm
- Complex ceramic-based designs possible
- Performed initial curing experiments of dUO_2 loaded resins – work ongoing
- Suitable for metallic powders
- DLP chip *projects* 405nm light to cure entire layer at once.
- Much higher solid loading possible in curable resin – higher green & final densities.
- Over 99%TD achievable







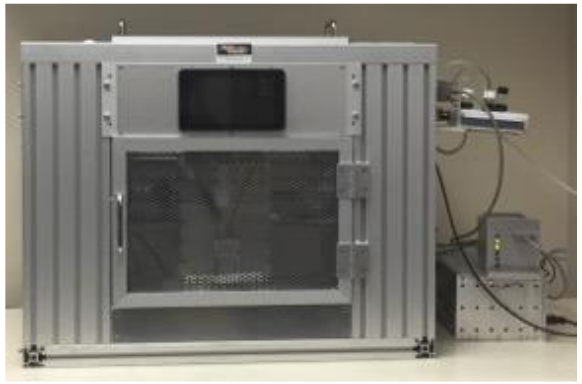


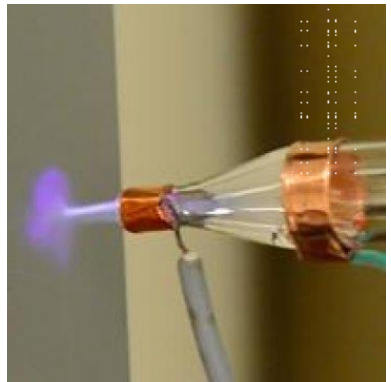
Field Assisted Sintering

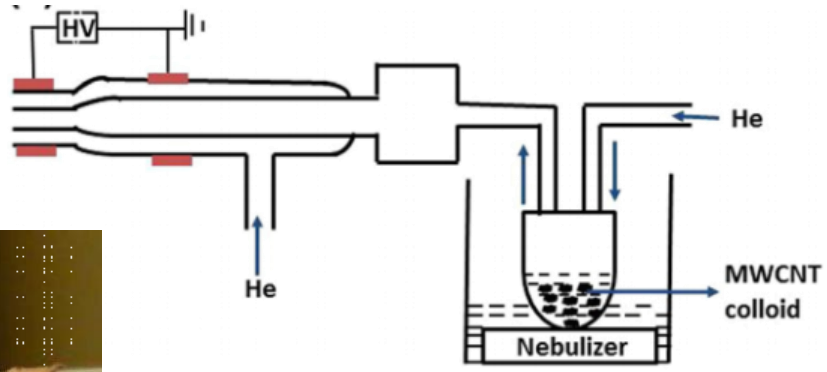
- Spark Plasma Sintering
  - 10,000 amps sintering current & 25 ton axial load
  - Thermocouple & pyrometer feedback control
- Near net shape sintering driven by die dimension
- Fast consolidation of materials to near theoretical densities
- Large specimen geometries up to ~75mm diameter
- An area where INL is putting significant investment for research and scale-up

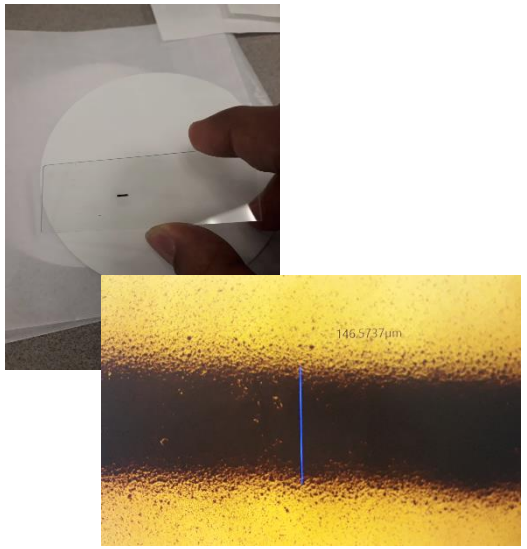
Direct Ink Writing

- Plasma Jet Printer
  - Able to simultaneously print and sinter
  - Direct write printing of wide range of materials including organics, inorganics, metals, metal oxides and polymers
  - ~2D printer, able to print fine lines and films



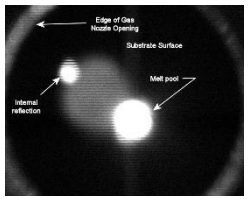


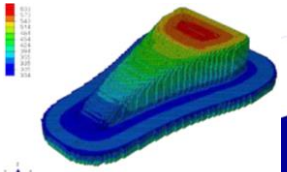


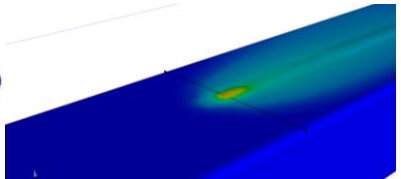


Advanced Manufacturing projects at INL

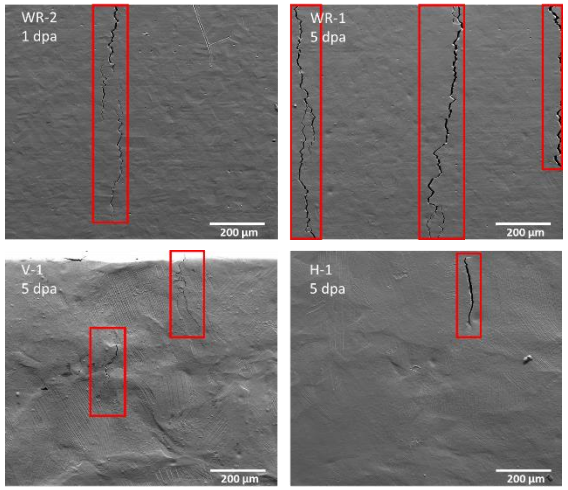
- Intelligent Additive Manufacturing
  - Objective: Develop instrumentation for in-situ monitoring and feedback control, and modelling/simulation tools, all of which provide process control for reliable and consistent properties of printed material
  - Optical camera provides feedback on meltpool size and shape
  - Examining effects of laser power, powder feed rate, stage speed, hatch spacing, etc.
  - Computation fluid dynamics pairs with phasefield and finite element analysis



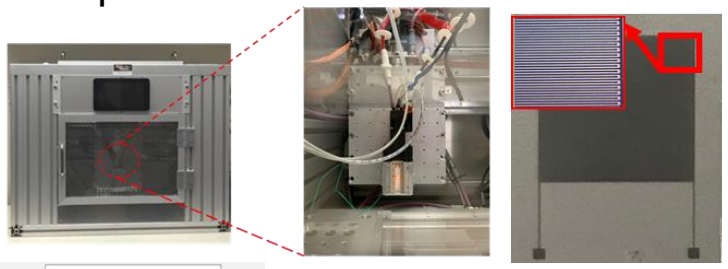


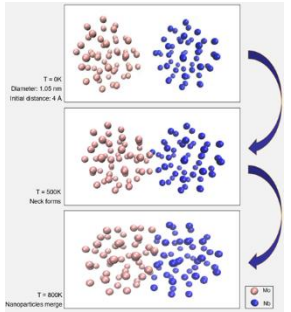


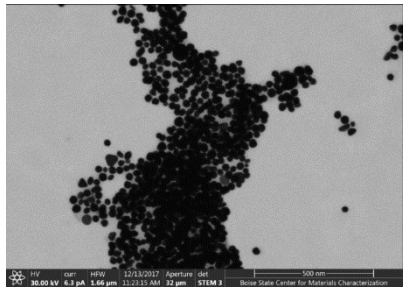
- Advanced Manufacturing for Novel Fuel and Structural Components
  - Objective: Develop AM techniques for fabricating novel fuel/cladding and structural components
  - Irradiation assisted stress corrosion cracking was examined for AM and wrought material, the AM was more resistant to cracking



- Advanced Manufacturing for In-Pile Instrumentation
  - Objective: Develop AM techniques for novel sensor/instrumentation production for use in test reactors
  - Combining ink development, combinatorial materials science studies, novel printing techniques and modelling to produce robust/reliable sensors

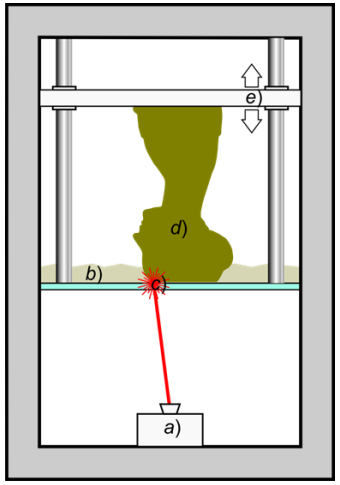




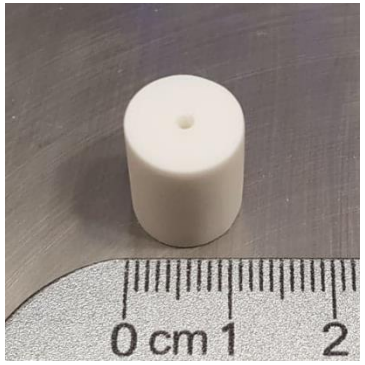


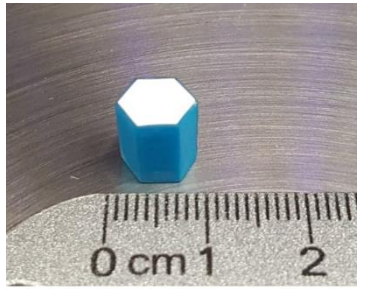
Stereolithography (SLA)

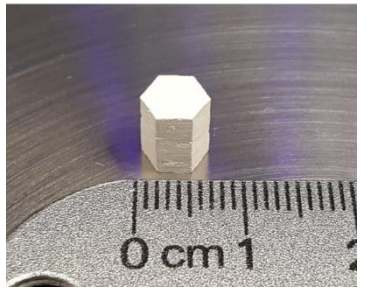
- Laser (405nm) *sketches* each layer pattern in ultraviolet (UV) curable resin.
- Resins loaded with ceramic powder
- Highly detailed parts with complex geometries possible
- Printed parts undergo debinding and sintering
- Printing of burnable molds for injection molding
- Densities up to 95%TD achievable



SLA Schematic







Additional Capabilities

- Crystal Grower
  - Customized for high temperature applications
  - Up to 25 mm diameter

  **basic science research*
- Precision Laser Welding system
  - 700 W lasing power
  - Paired to custom glovebox enclosure
  - Multi-axis lasing head & rotational stage
  - Up to 2.5 in diameter x 12 ft length

  **weld enclosure of critical materials, e.g. radiological fuels/materials. Certified welds for irradiation experiments.*
- Isostatic Dry-Bag Press
  - High isostatic load

  **large, single rodlet pressing*

Crystal Growing
courtesy of Thermal Technologies

Laser Welding System
courtesy of IPG

INL Materials Science and Engineering Department

- **Harsh environment material testing**
  - Metals, welds, graphite, ceramics
  - Elevated temperature testing
  - Salt fog/controlled gas environments
  - High temperature/pressure water autoclaves
- **Modelling and simulation**
  - Variety of languages and frameworks
  - Micro-Meso-Macro scale
  - Solids/microstructure to computational fluid dynamics
- **Characterization**
  - Electron microscopy
  - X-ray
  - Optical/Laser based