Sandia National Laboratories

MULTI-MATERIAL ADDITIVE MANUFACTURING

A SHOWCASE OF RECENT DEVELOPMENTS

SANDIA'S INNOVATION MARKETPLACE

APRIL 2022

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INTELLECTUAL PROPERTY MAGAZINE

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Why Work with Sandia?

Leverage World-Class Technology and Research

For more than 70 years, Sandia has delivered essential science and technology to resolve the nation's most challenging security issues. A strong science, technology, and engineering foundation enables Sandia's mission through capable research staff working at the forefront of innovation, collaborative research with universities and companies, and discretionary research projects with significant potential impact.

The Best and Brightest

In keeping with our vision to be the nation's premier science and engineering laboratory for national security and technology innovation, we recruit the best and the brightest, equip them with world-class research tools and facilities, and provide opportunities to collaborate with technical experts from many different scientific disciplines.

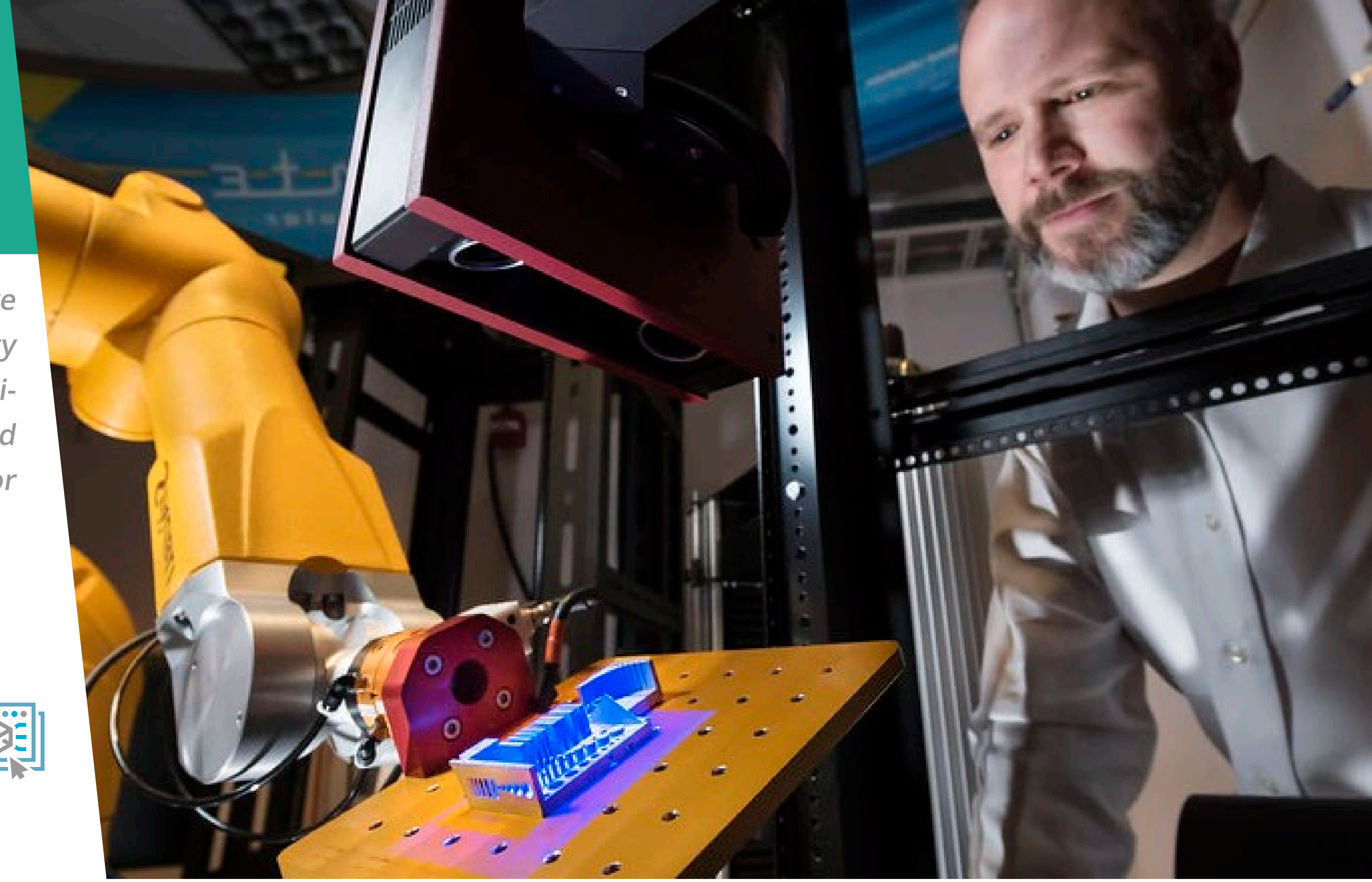
The excitement and importance of our work, an exemplary work environment, partnerships with academia, industry, and government, and our record of historic contributions help us to attract exceptional staff. Our employees are recognized by their professional peers for their outstanding contributions.

Exceptional service in the national interest

Contents

MULTI-MATERIAL ADDITIVE MANUFACTURING AT SANDIA

Sandia National Laboratories has spent decades developing new additive manufacturing (AM) tools and processes to fulfill its unique national security mission where reliability and quality are of utmost importance. A multi-disciplinary approach in analysis-driven design, materials reliability, and multi-material AM uniquely positions Sandia to make strong contributions for national security as well as commercial applications.



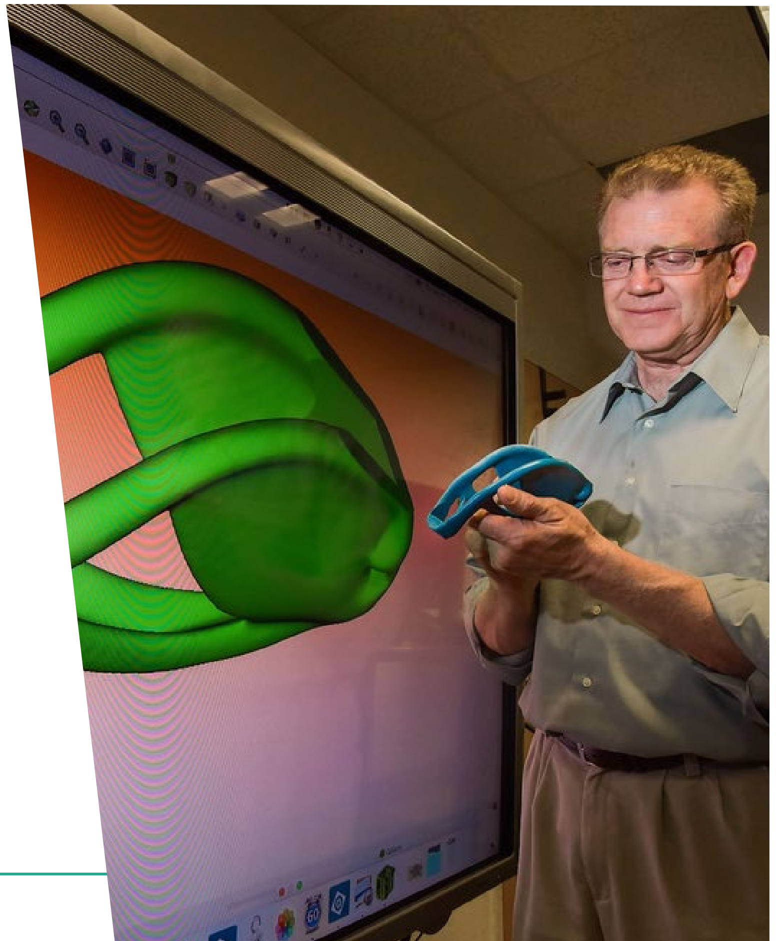
Partnership History

Sandia was an early leader in the additive manufacturing field in the 1980s for rapid prototyping of defense and aerospace components.

In the mid-1990s, Sandia developed, patented, and successfully commercialized one of the first metal AM technologies, Laser Engineered Net Shaping (LENS). Known for its low-degradation and near net-shape metal parts, LENS is now used for rapid prototyping and manufacturing for industries worldwide.

Since 1989, Sandia has investigated experimental and computational techniques for reducing lead time and overhead in prototyping. Formed between Sandia and several companies, the collaborative research and software development within the FASTCAST consortium dramatically shortened lead times and improved outcomes for the precision casting industry.

Around the same time as LENS, Sandia created and commercialized Robocasting, which uses robotics to control the deposition of ceramic and metal composites. Robocasting unlocked cheaper and faster AM fabrication of complex ceramic parts with limited machining. The company Robocasting Enterprises spun-off from the Labs in 2007.



FACILITIES & CAPABILITIES

Sandia has multidisciplinary science and engineering capabilities that result in best-in-class advancements for additive manufacturing (AM).

Advanced Materials Laboratory

Sandia is home to the Advanced Materials Laboratory (AML), a state-of-the-art facility designed to foster research across the AM spectrum, from creating materials with unique properties, to process and equipment research and development (R&D), to the manufactuing and testing of prototype hardware. Sandia's AML employs direct-write and laser-printing platforms to develop custom-engineered materials and scalable multi-material approaches for printed electronics and hardware.

This unique Sandia facility is located on the campus of the University of New Mexico (UNM) and provides solutions for a wide range of applications.

NEW AT THE AML:

Aerotech 5-Axis Tool

This new capability expands on Sandia's ability to deliver cutting-edge processing solutions for printed electronics applications.

Materials Science and Engineering (MSE) Center

The Materials Science and Engineering (MSE) Center at Sandia provides knowledge of materials structure, properties, and performance and the processes to produce, transform, and analyze materials to ensure mission success for our customers and partners, both internal and external to Sandia. The MSE is comprised of several laboratories, each providing unique capabilities with access to world-class equipment, technicians, and researchers.

AM EQUIPMENT, TECHNIQUES, & MATERIALS

Sandia's ongoing R&D efforts in AM result in advancements that are helping to redefine the current limits of equipment, techniques, and approaches.

AM PRINTHEAD FOR EXOTIC MATERIALS APPLICATIONS

A customized printhead for safe and high-quality AM of energetic materials.

AM printing of piezoelectric materials in the form of sensors is potentially useful for the areas of integrated and personal smart devices in industries from aerospace to bioscience; however, factors such as material degradation, arcing, and burning during fabrication continue to present barriers for production-scale efforts.

Recent adaptations to fused deposition modeling (FDM) AM techniques have created pathways for the printing of exotic materials, including those that are electrically or magnetically oriented or chemically endo- or exothermic. Sandia researchers have developed a printhead customization for existing FDM printers that reduces undesirable material effects during the fabrication of energetic materials. The printhead dissipates excess charge and mitigates arcing between the extrusion nozzle and the build plate by coupling a configurable arc suppressor to the extrusion nozzle. Arc suppressing gas can be optionally introduced into the print region for further mitigation.

Technical benefits:

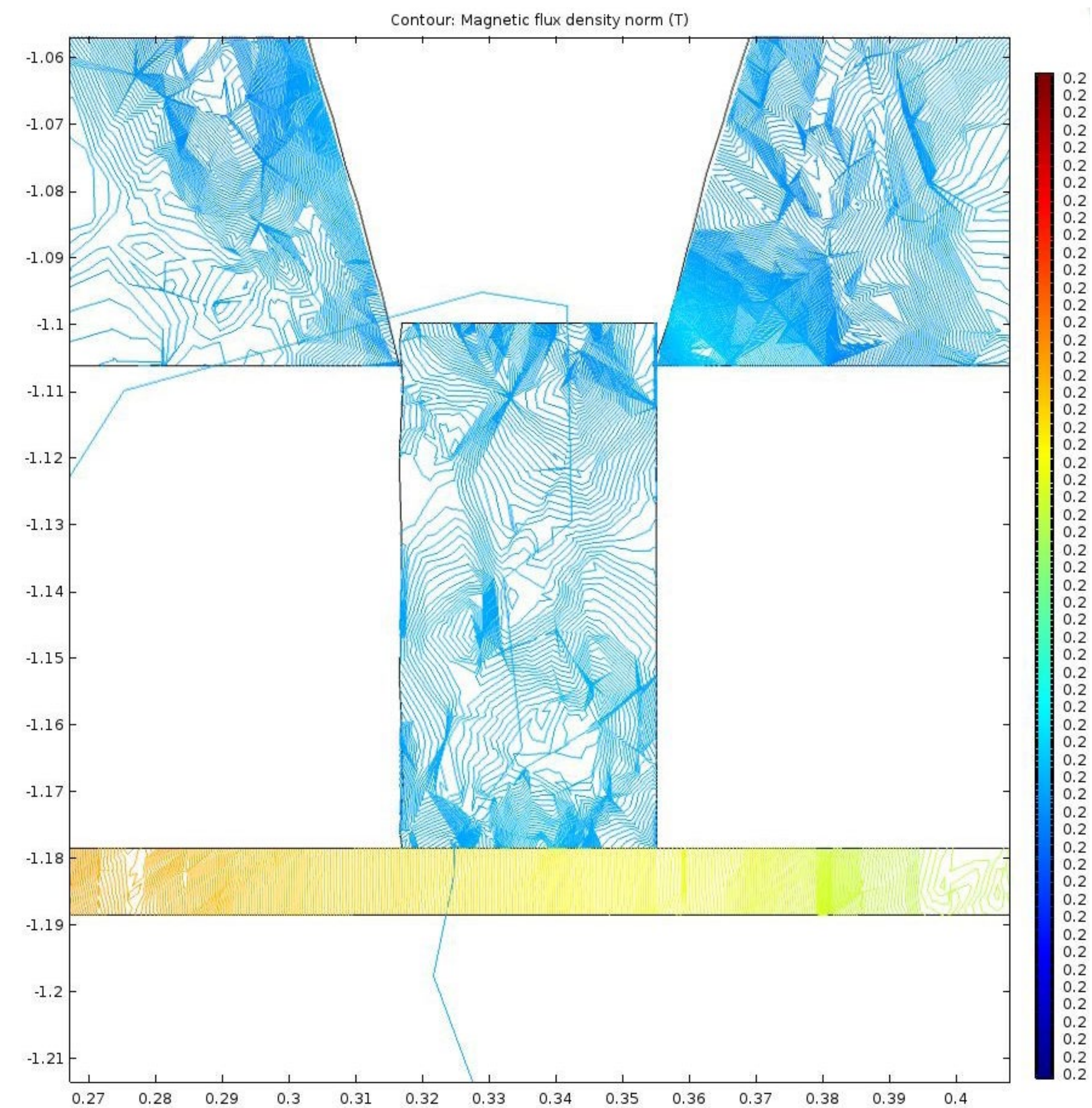
- Mitigates burning and arcing during forming of energetic materials
- Option to dispense arc-suppressing gas at the nozzle for direct polymerization of materials
- Inhibits material degradation
- Improves safety

AM Approach: Fused Deposition Modeling (FDM)

US Patent: 11,084,211

Technology Readiness Level: 3

Technology ID: SD 14128

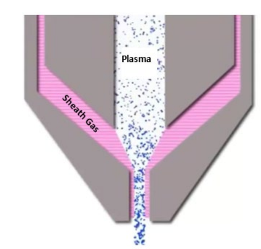


Cross-section of an AM printhead leveraging magnetic materials

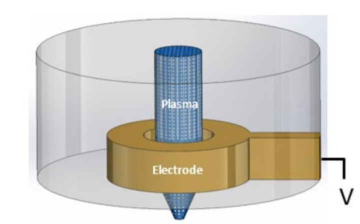
PLASMA MICRONOZZLE ADAPTER FOR HIGH-RESOLUTION, MULTI-MATERIAL PLASMA JET PRINTING

A micronozzle adapter capable of printing line widths and thicknesses 10x finer than existing 3D plasma jet printers.

Plasma jet printing is well positioned for electronics manufacturing due to its ability to print a wide range of materials onto diverse substrates from a single platform. However, advancements are needed before the small spot sizes and high print resolutions required for advanced electronics can be attained.



A shealth gas focuses the plasma into a tight beam



A sudden change of voltage gradient focuses the aperature lense

Sandia researchers have developed a MEMS-based printhead adapter for existing plasma jet printers that uses lensing electrodes to focus the plasma beam and control deposition spot size. Sandia's plasma micronozzle adapter enables the printing of smaller and finer electronic features, such as high-density chip copper interconnects, integrated circuit (IC) packages, and integrated conductors.

Technical benefits:

- MEMS-based printhead adapter
- Compatible with existing commercial plasma jet printers
- Prints 10x finer line widths than existing technologies
- Prints a wide range of materials
- Single platform offers simplified operations and extended run times for commercial applications

AM Approach: Plasma Jet Printing

US Patent: Pending

Technology Readiness Level: 2

Technology ID: SD 14959.1

ARCHITECTED POROUS STAMP FOR LIQUID TRANSFER PRINTING

An architected porous stamp fabricated using multiphoton lithography (MPL) can achieve very fine, tunable features and exceptional control in liquid transfer printing.

Mass production roll-to-roll printing techniques such as flexography, gravure, and offset are undergoing re-examination for their suitability in the emerging area of printed electronics. These methods rely on high speed ink-transfer mechanisms using direct print-form to substrate contact. Commonly occurring defects such as haloing, featuring, and bridging can impact the performance of printed materials for electronics applications. To improve the viability of these approaches, strategies are needed to increase print fidelity and film uniformity.

This Sandia-developed microscale print form can achieve very fine, tunable features and exceptional control during liquid transfer printing processes. The stamp is designed with layered Poisson's ratio to dictate capillary forces that effectively meter fluid transfer through architected porosity. The print form was fabricated using multiphoton lithography (MPL), a microscale AM technique that enables submicron feature sizes. This new technique offers advanced control of fluid uptake and dispensing and can be used to develop more sophisticated liquid transfer processes for emerging applications such as solar cell metallization and printed circuits.

Technical benefits:

- Improved throughput, efficiency, and performance in mass production
- Reduces defects and blemishes

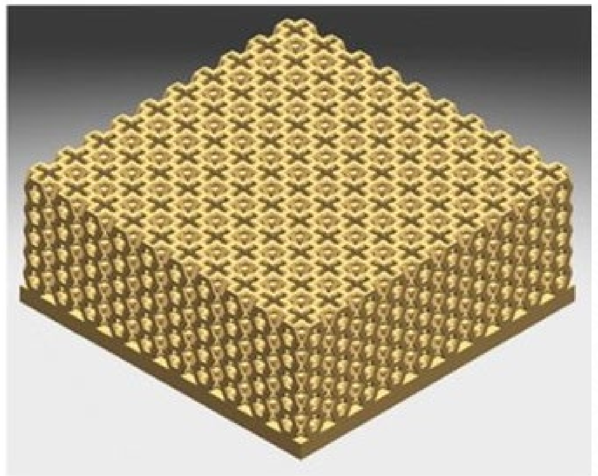
AM Approach: Flexographic Printing

US Patent: Pending

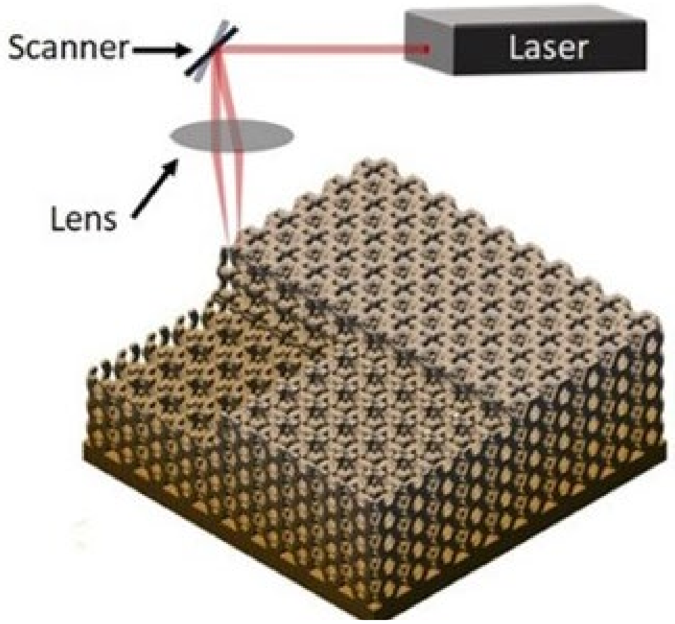
Technology Readiness Level: 3

Technology ID: SD 15244

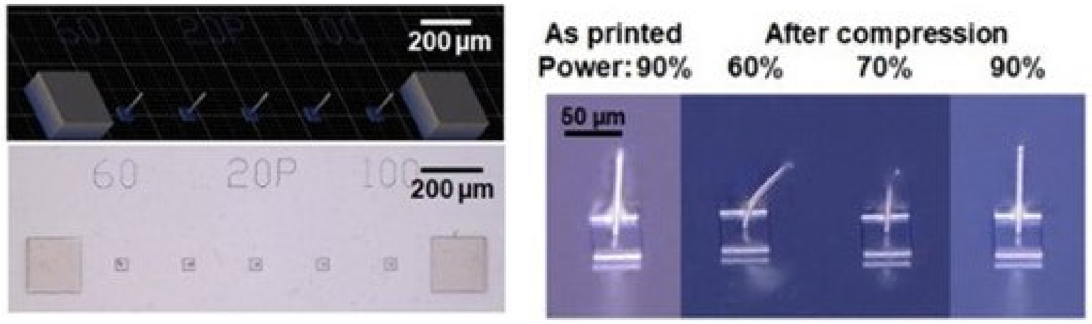
CAD Design of Printing Form



MPL Fabrication



Testing



AM CRYSTALLINE MATERIALS

Highly localized, site-specific AM of high power conversion efficiency (PCE) crystalline materials for semiconductors and functional devices.

Semiconductors are foundational materials that underpin all modern electronic devices ranging from integrated circuits, LEDs, and photovoltaics. One class of crystalline semiconductor material that has gained widespread attention is broadly known as organometallic perovskites. Perovskites have beneficial properties such as high optical gain, long carrier lifetimes, and tunable wavelengths which can enable remarkable power conversion efficiencies (PCE). Despite its promise, there are several challenges to incorporating organometallic perovskite into functional devices, including environmental sensitivity and degradation of physical properties of the crystalline material during processing.

Researchers at Sandia have developed a way to additively manufacture perovskite directly onto devices by thermally inducing crystal growth using a laser direct write approach. This technique addresses the degradation issues that result from exposure to the mixed solvents, photoresists, and etchants found in typical lithographic processes. The ability to direct-write crystalline materials with site-specific accuracy eliminates the need for typical lithographic processes and frees up design space. This technique for highly localized, site-specific AM of crystalline materials could greatly enhance the quality and efficiency of high PCE perovskite photovoltaic devices.

Technical benefits:

- Prevents degradation of crystalline materials
- Frees up design space due to the ability to direct-write with site-specific accuracy
- Flexible placement of crystal growth site supports growth in any pattern

AM Approach: Laser Direct-Write

Patent: 10,214,833

Technology Readiness Level: 4

Technology ID: SD 13887

COINAGE METAL NANOPARTICLES FOR NANOINKS

A simple and scalable method of generating high-quality coinage metal nanoparticles for the rapid, high-volume production of nanoinks.

Printed and flexible electronics are a fast-growing area of interest with commercial applications ranging from wearables, smart packaging, photovoltaics, to lighting and displays. Nanoparticle-based functional inks (nanoinks), particularly those with conductive properties, play a significant role in the market realization of this emerging area.

Sandia has developed a simple and scalable method of generating high-quality coinage metal nanoparticles that can address the need for the rapid, high-volume production of nanoinks. The technique was demonstrated with copper using a xylene-based solvent and a hyperdispersant. Dynamic light scattering (DLS), powder X-ray diffraction (PXRD), and transmission electron microscopy (TEM) studies were used to confirm nanoparticle size and qualities measuring 6-16 nm at temperatures between 160-185° C, depending on scale. The resulting nanoinks were found to support architectures with high-quality copper patterns in aerosol and inkjet printing applications in the sub 50 micrometer range.

Technical benefits:

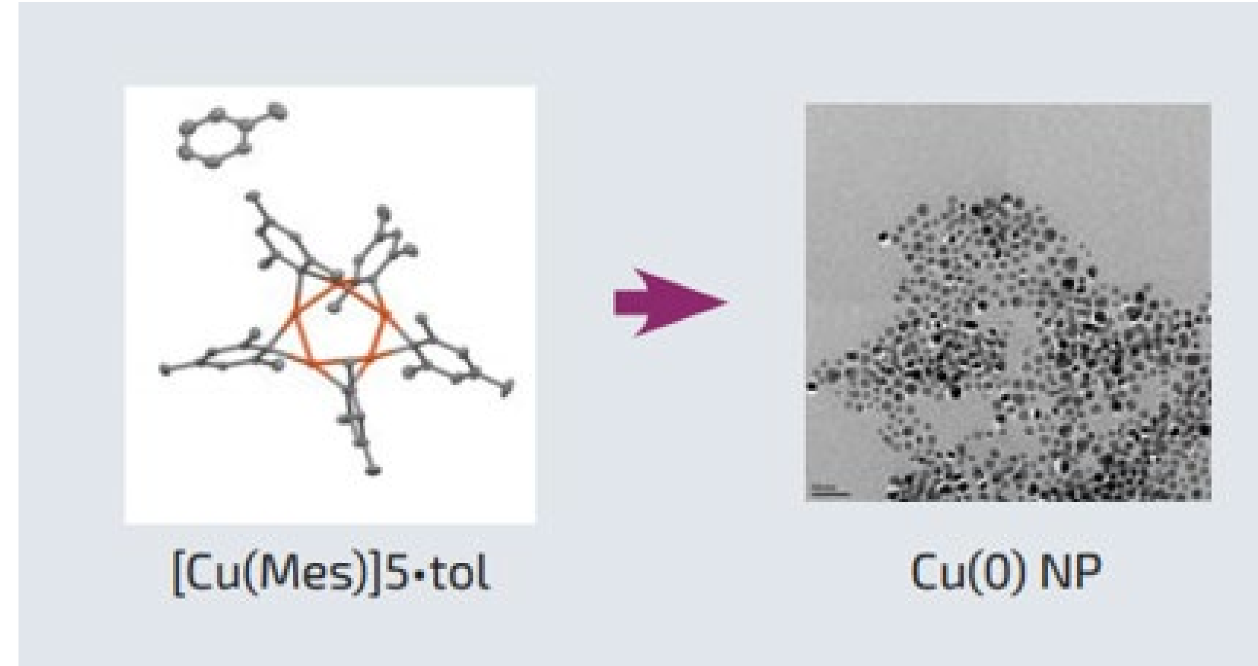
- Aerosol and inkjet compatible
- Air-stable
- Reduced time and temperature compared to other methods
- Low viscosity (sub 50 micrometer range)
- Scalable for large-volume requirements
- Compatible with multiple metal types (copper, silver, and gold)

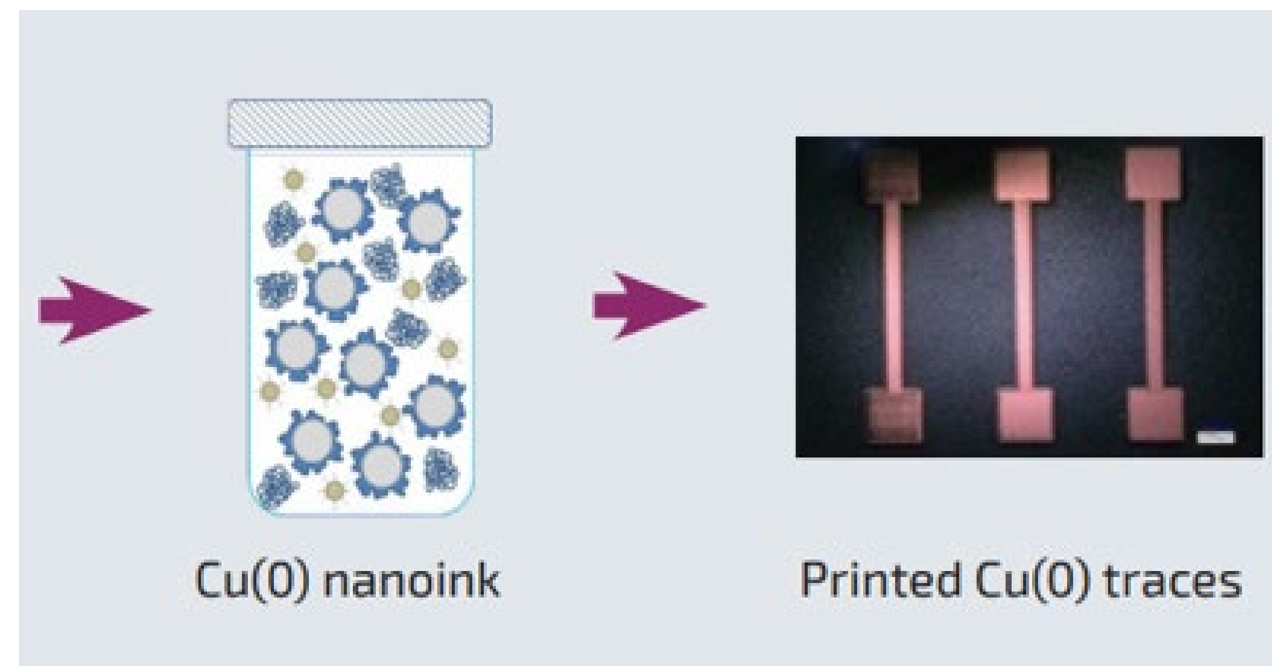
AM Approach: Material Jetting

US Patent: Pending

Technology Readiness Level: 2-3

Technology ID: SD 14202.1





METAL HYDRIDE NANOINKS

Metal hydride nanoinks for printing electrically conductive, titanium-based patterns under ambient conditions.

The most common metallic inks are composed of nanoparticles or molecular precursors that are cured after printing to yield conductive traces; however, most metals are prone to oxidation, especially in the nanoparticle state which limits their utility. The ability to print air-stable, conductive metals is currently restricted to coinage metal nanoparticles. Additional nanomaterials are desired by industry to enable novel application areas.

Researchers at Sandia National Laboratories have invented a method for liquid-phase printing of electrically conductive, metal-based patterns under ambient conditions using a stable titanium hydride nanoparticle precursor. This method of using metal hydride nanoparticle inks presents an alternative to traditional metal inks, broadening the scope of printable conductors and adding value to energy, sensing and catalysis applications. In comparison to traditional printed metals, titanium exhibits increased stability to environmental stressors, which makes it useful for electrochemical, biological, and high-temperature applications.

Technical benefits:

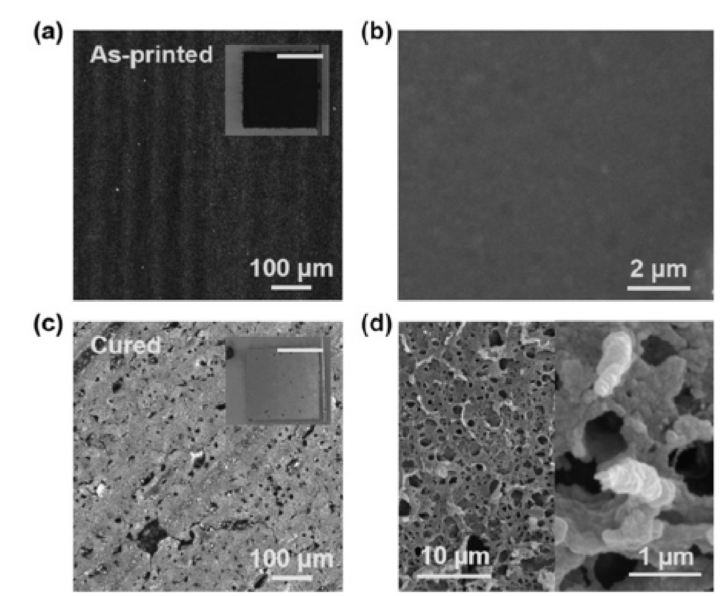
- Aerosol deposition yields high-resolution patterns (20-100 micrometer line width)
- Metal hydride nanoparticles <200 nm in diameter
- Pulsed photonic curing results in an electrically conductive network of particles

AM Approach: Material Jetting

Patent: Pending

Technology Readiness Level: 2-3

Technology ID: SD 14965



Printed TiH2 ink at various magnifications

HIGHLY CONDUCTIVE, HIGH-RESOLUTION PRINTED ELECTRICAL TRACES AND COMPONENTS

A two-step AM approach for conformally printing highly conductive, high-resolution electrical traces and components.

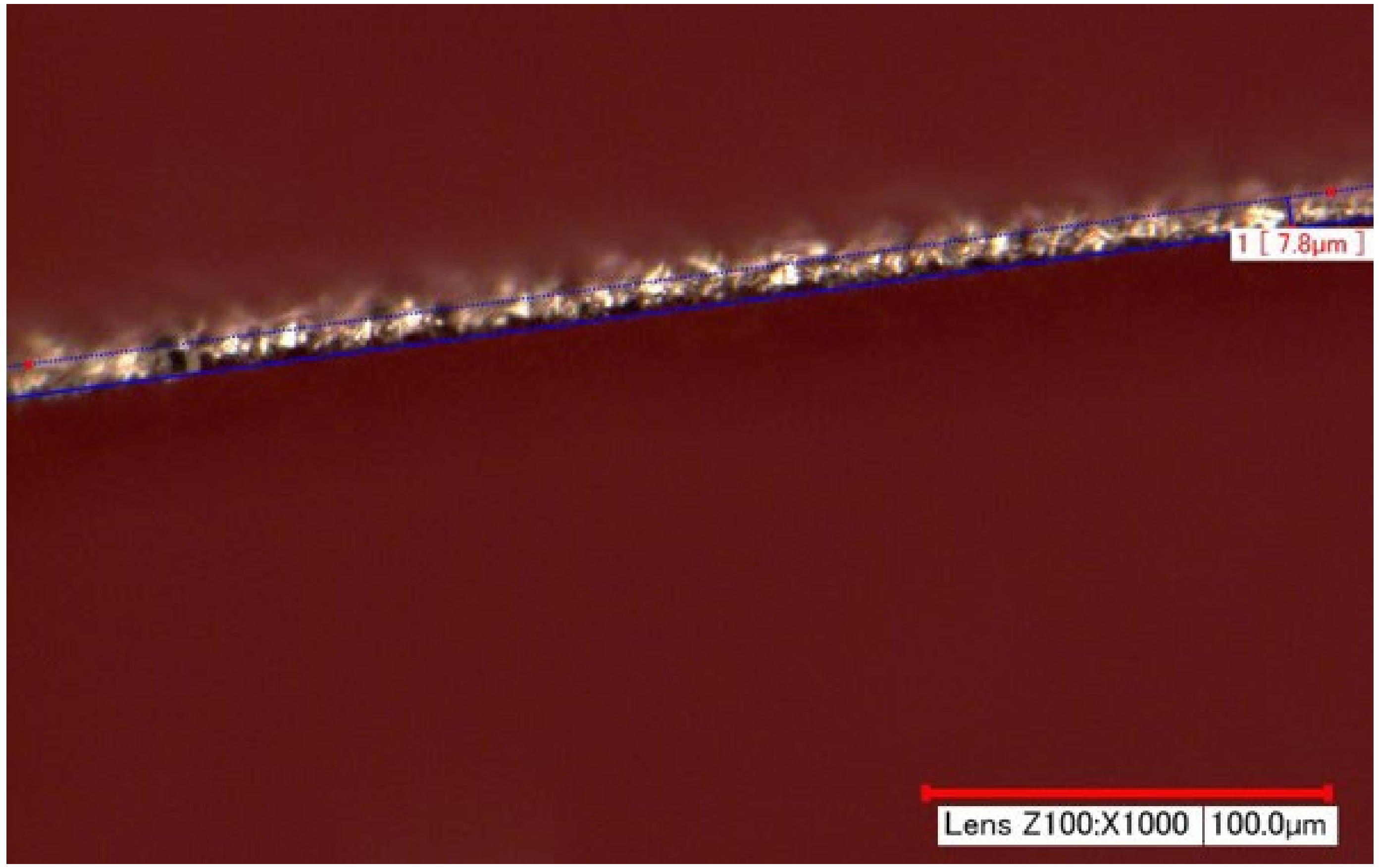
Emerging trends in advanced electronics are creating new demand for high-conductivity components that can be formed over varied or uneven surfaces. To date, high-resolution (10 micron) traces have been produced with aerosol jet printing (AJP) but so far these methods cannot achieve the conductivity needed.

Sandia researchers have developed a two-step AM approach for printing high-resolution, highly conductive traces using aerosol jet printing (AJP) and electroplating processes. In the first step, an AJP makes multiple passes to deposit a thin layer of conductive seed material. In the second step, the seed layers are subject to an electroplating process to refine the desired bulk and thickness of the electrical traces.

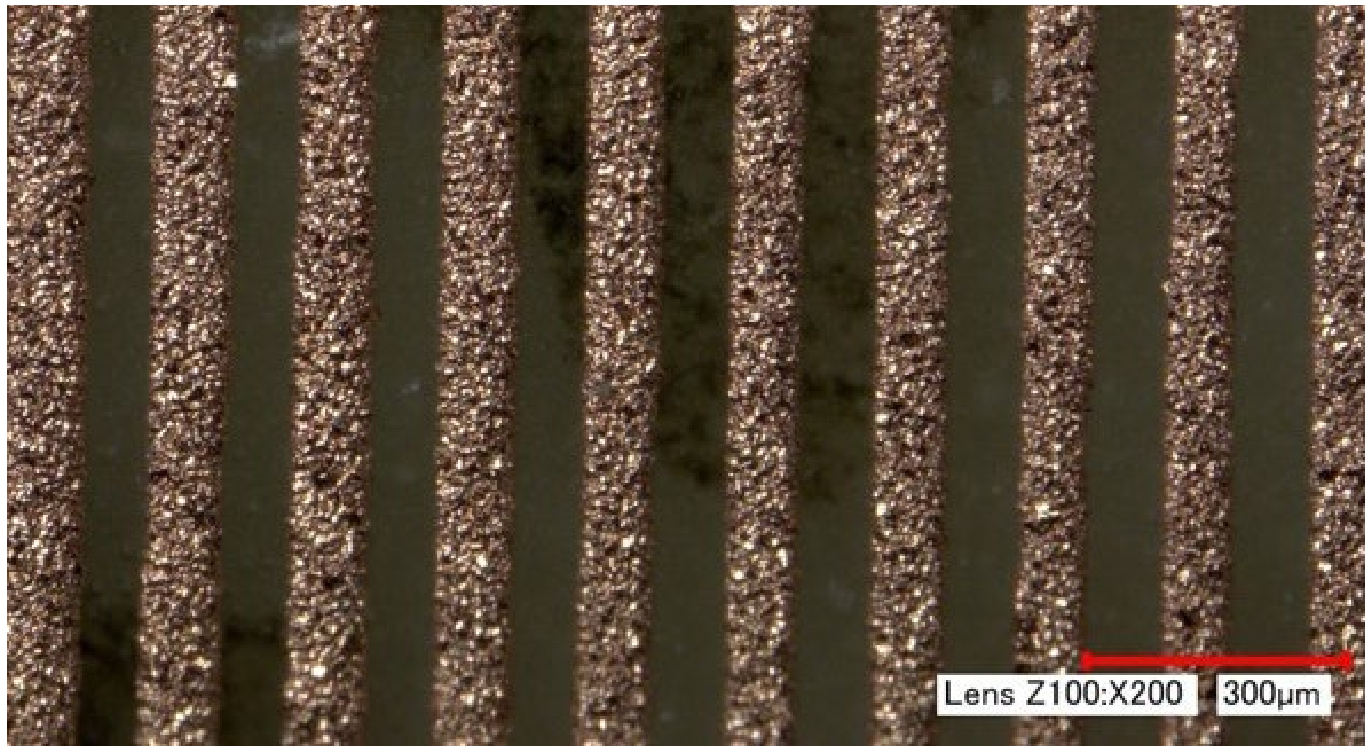
The high-resolution printed metallic materials can attain freestanding, stretchable, and/or flexible features as desired. This new method overcomes existing barriers in AJP methods and offers a promising pathway for diverse commercial applications such as forming transformers, producing radio frequency (RF) interconnects and antennas, printed electrodes, and more.

Technical benefits:

- Conformal printing of fundamental trace feature sizes from 10 to 100 microns
- Achieves 100-fold decrease in trace resistance for transformer components and multi-level interconnects
- Improved conductivity and uniformity
- Tunable properties: Freestanding, stretchable, flexible, and high-resolution properties
- Reduced energy losses



Cross section of printed traces shows a thickness of 8-microns



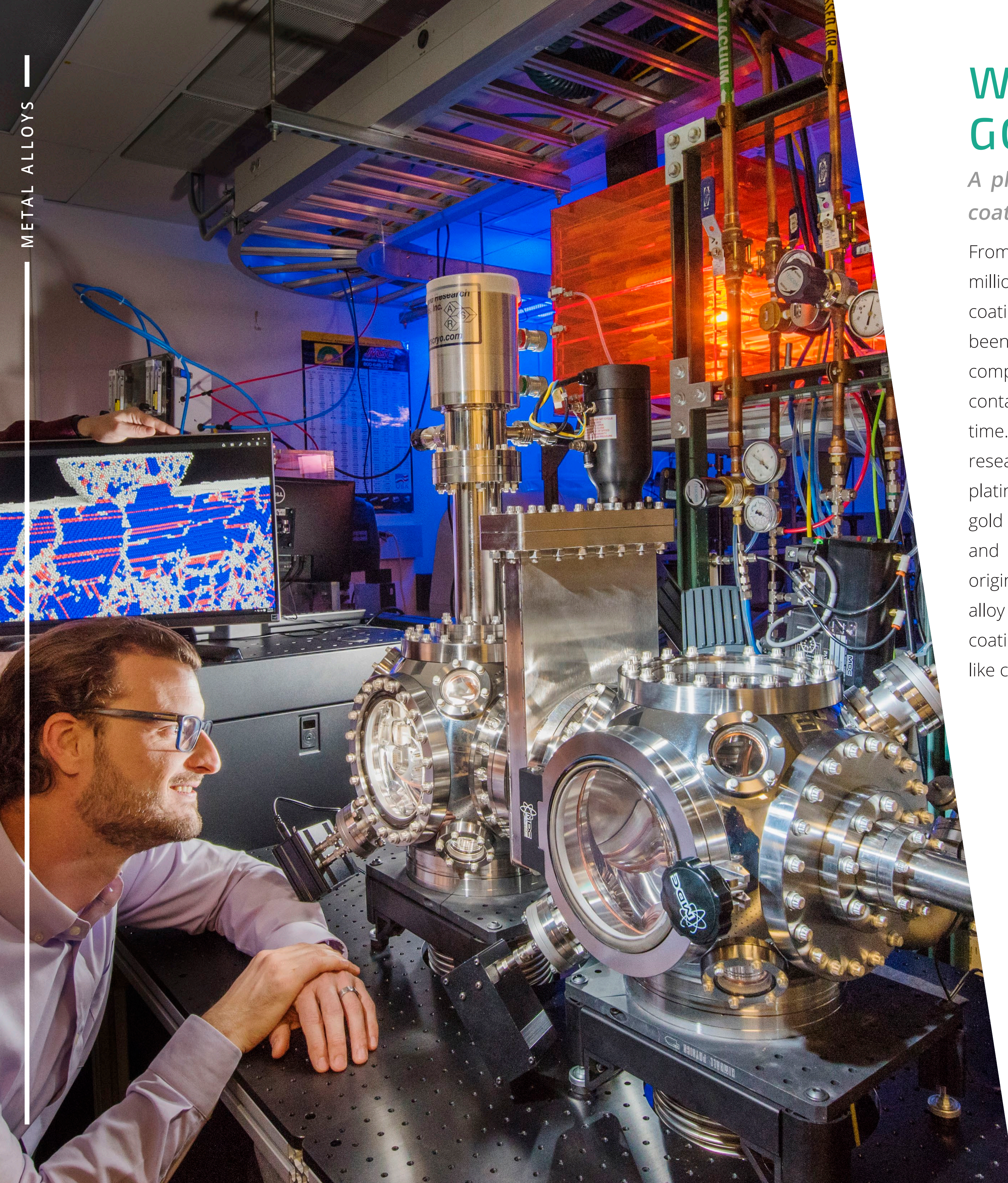
Copper coated Ag lines deposited after 3 hours

AM Approach: Aerosol Jet Printing

Patent: Pending

Technology Readiness Level: 3

Technology ID: SD 15427



WEAR-RESISTANT PLATINUM GOLD ALLOY

A platinum-gold alloy demonstrating 100x higher wear life than conventional coatings with superior electrical conductivity.

From cell phones to satellites, industry spends millions on traditional gold alloy electrical contact coatings. While gold and other metal alloys have been an industry standard to protect metal components from wear due to metal-on-metal contact, they still experience deterioration over time. Using a novel synthesis approach, Sandia researchers developed an ultra wear-resistant platinum gold (Pt-Au) alloy that can replace gold alloys for improved durability, longevity, and reduced costs in electronic devices. While originally developed for electronic coatings, this alloy also has potential applications in tribological coatings due to its ability to produce a diamond-like carbon lubricant in service conditions.

Technical benefits:

- 100x more durable than traditional contact coatings
- Easy to apply using conventional deposition methods
- Stable at high temperatures (~500 °C)
- Self-healing in anoxic environments enables formation of a diamond-like carbon lubricant

AM Approach: Electrodeposition

US Patent: 10,763,000

Technology Readiness Level: 4

Technology ID: SD 14332

ENHANCED FUNCTIONAL ALLOYS WITH HIGH STRENGTH AND DUCTILITY

A technique for tailoring the mechanical properties of traditionally low-strength and low-ductility alloys using laser beam powder bed fusion (LB-PBF) AM.

AM Approach: Laser Powder Bed Fusion

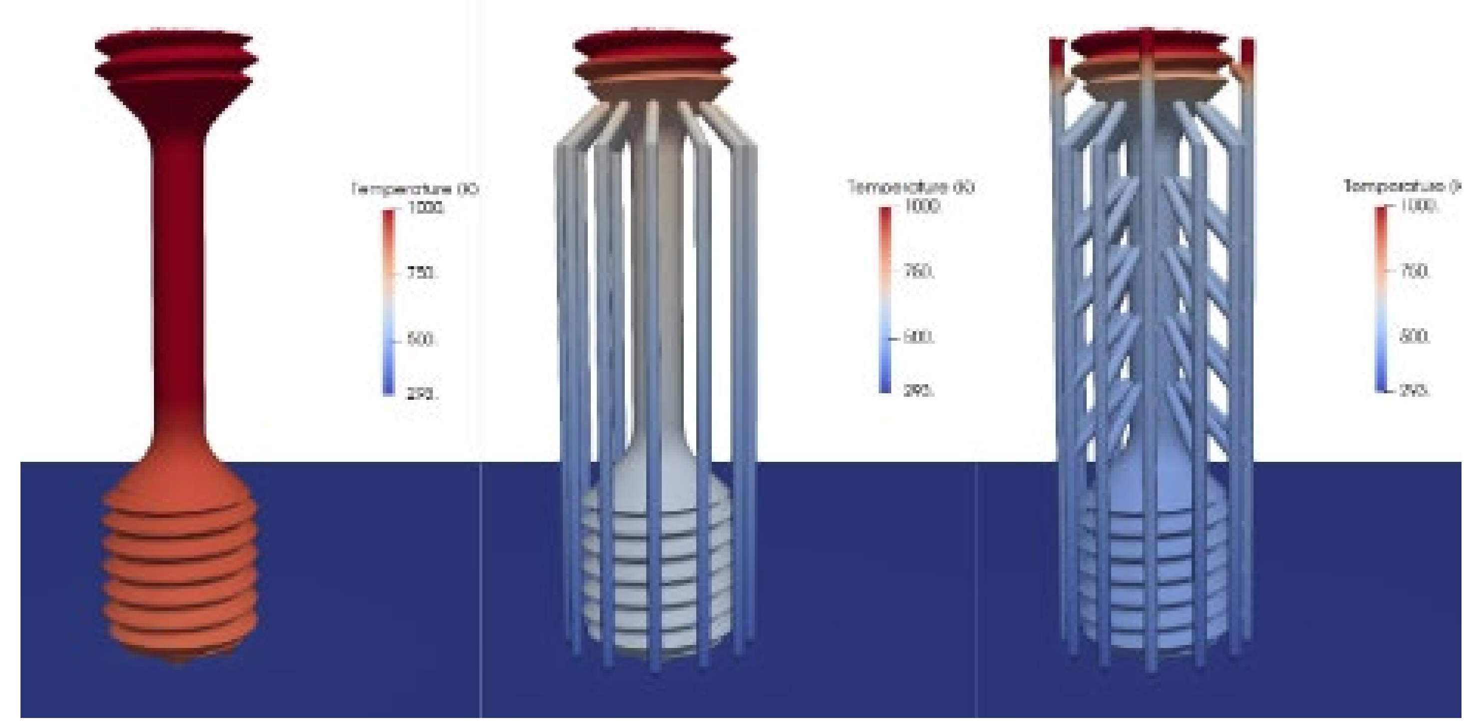
US Patent: Pending

Technology Readiness Level: 4

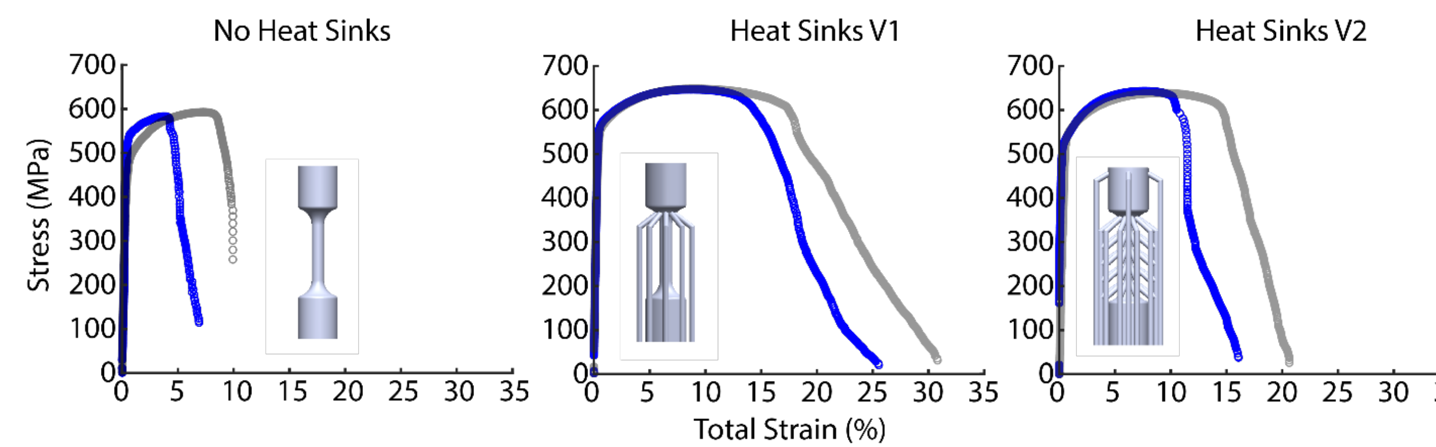
Technology ID: SD 15173

AM offers unprecedented design freedom that can lead to novel materials development. Intermetallic alloys have useful magnetic properties such as high permeability, low coercivity, and high-saturation induction that are ideal for electromagnetic devices, particularly those in aerospace applications. However, when they are conventionally manufactured, these alloys are notoriously brittle and have poor mechanical properties that have impeded their commercialization in bulk form.

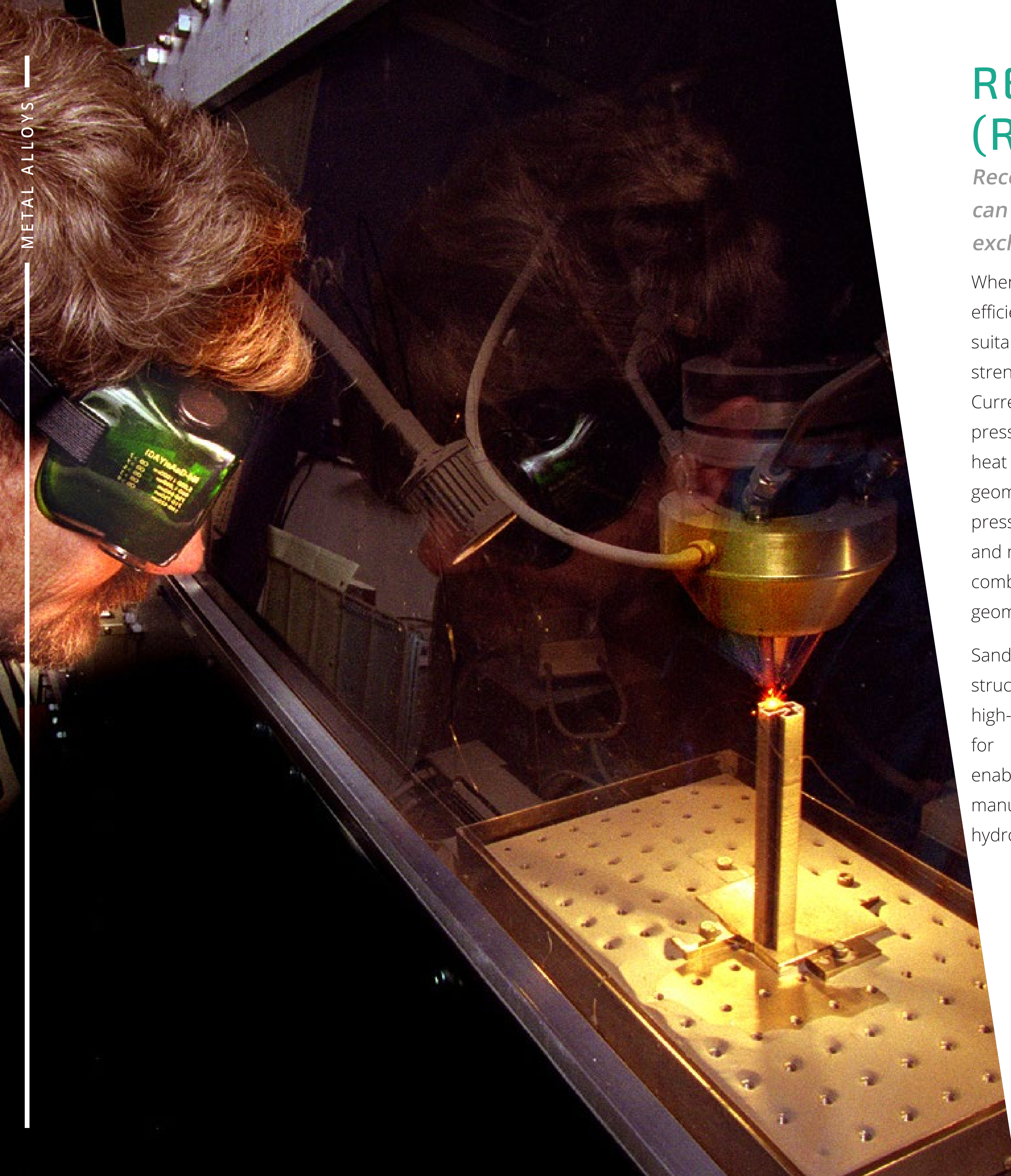
Researchers at Sandia National Laboratories and Lehigh University developed a technique to tailor the mechanical properties of traditionally low-strength and low-ductility alloys by introducing removable heat sink artifacts using laser beam powder bed fusion (LB-PBF) AM. The technology enables the end-user to circumvent dependence on conventional manufacturing to achieve the desired material structure and function. This potentially impacts aerospace technologies and industries that would benefit from high-strength and high-ductility, soft magnetic alloys—such as power generating units, internal generators for propulsion engines, and magnetic bearings.



A representation of the different thermal histories for the three designs at a location well within the upper grip at 20,000 s into the simulation. Notably, the V0 design had a higher temperature throughout the specimen height compared to V1 and V2.



Tensile stress versus strain curves for the three AM design approaches. Specimens processed without heat sink struts exhibited significatnly lower ducitility than those produced with artifacts. Note, blue and gray tensile curves are representative tensile tests.



REFRACTORY HIGH ENTROPY ALLOY (RHEA) COMPACT HEAT EXCHANGER

Recent breakthroughs in hybrid advanced manufacturing and advanced alloys can significantly extend the temperature and pressure operational range of heat exchangers.

When it comes to their material properties, high-efficiency compact heat exchangers require a suitable combination of creep, high-temperature strength, oxidation resistance, and thermal shock. Current heat exchanger designs incur costly pressure drops while only marginally increasing heat transfer. The ability to manufacture complex geometries is needed to reduce this wasteful pressure drop. However, conventional material and manufacturing methods cannot achieve this combination of material properties and complex geometries.

Sandia researchers have identified thermal and structural properties of advanced refractory high-entropy alloys (RHEAs) as candidates for high-temperature heat exchangers enabled by combined additive and subtractive manufacturing as well as surface-engineered hydrodynamic optimization. This technology achieves near net shape geometries that are currently impractical for conventional manufacturing, allowing the end-user to better control function through structure and material design. This is relevant in systems where improvements are limited by current state-of-the-art alloys' performance, such as conventional Ni-based superalloys.

Technical benefits:

- Reduces pressure drop in heat exchangers by 100–500%
- Extends high temperature allowable stress
- Achieves near net shape manufacturing

AM Approaches: Laser Engineered Net Shaping (LENS), Laser Beam Directed Energy Deposition (LB-DED), Laser Beam Powder Bed Fusion (LB-PBF)

Patent: Pending

Technology Readiness Level: 3

Technology ID: SD 14916.1

RAPID ELECTROPULSING METHOD FOR METALLIC PARTS

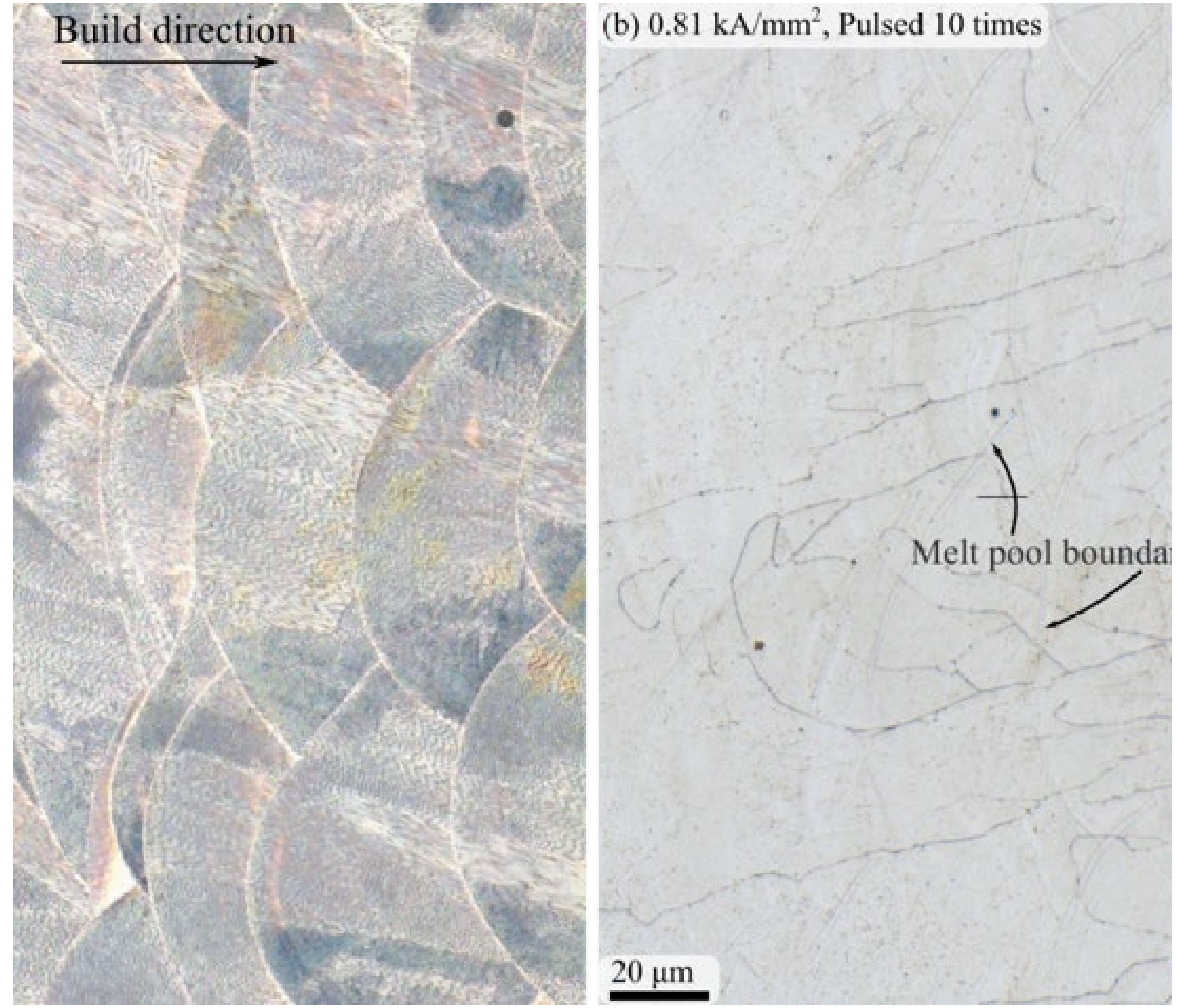
A rapid electropulsing method that reduces chemical micro-segregation in additively manufactured metallic parts in a fraction of the processing time.

AM Approach: Post-Processing
US Patent: Pending
Technology Readiness Level: 4
Technology ID: SD 15154

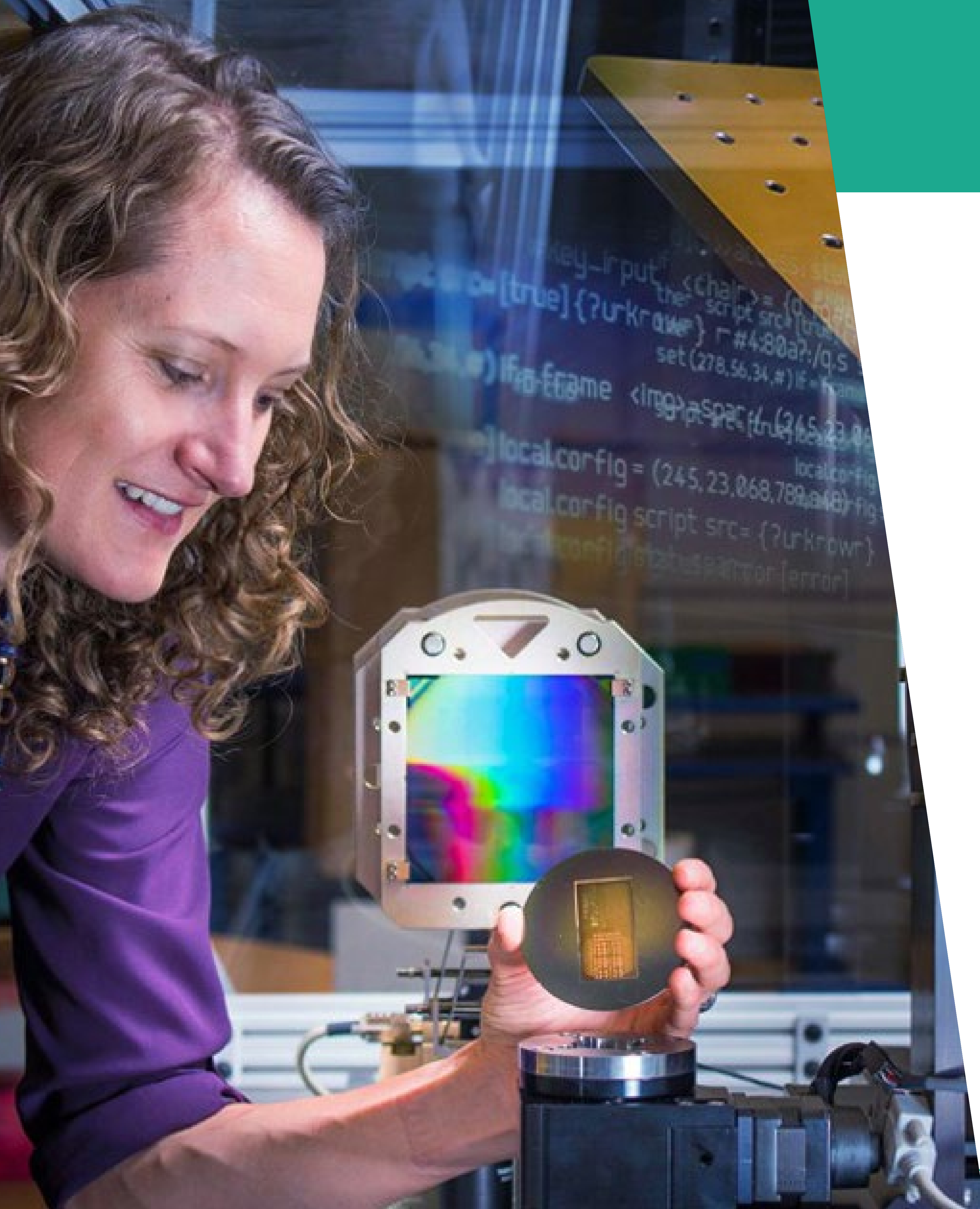
While AM methods allow for the fabrication of near net shape parts, the rapid cooling of each material layer produces microstructures with undesirable features. Post-build heat treatments are typically used to address these effects; however, thermal treatments of metallic AM parts have significant downsides such as part distortion, damage, and increased processing times. Sandia researchers have developed a rapid method to improve the quality of metallic AM parts by reducing chemical micro-segregation. By using short, high current density electropulses, the technique can treat metallic AM parts in a fraction of the processing time compared to conventional heat-treatment techniques.

Technical benefits:

- 10x faster processing of stainless-steel parts fabricated through selective laser melting (SLM)
- Enables target modification of a small area, rather than the entire part
- Improved efficiency, throughput, and part quality



Representative optical images of a 316 SS specimen electropulsed 10x show the significant reduction in chemical microsegregation associated with the electropulsing treatment.



PARTNERING WITH SANDIA

Sandia can offer access to world-class scientific knowledge, advanced technologies, and specialized research facilities through a variety of partnership types.

License Agreement

Sandia can work with industry, government, other national laboratories, and academia to find the right license agreement to fit their needs.

Technology Readiness Gross Receipts Initiative

The Technology Readiness Gross Receipts (TRGR) initiative provides New Mexico businesses the opportunity to work directly with scientists and engineers at Sandia or Los Alamos national laboratories.

Cooperative Research and Development Agreement

In a Cooperative Research and Development Agreement (CRADA), Sandia and one or more partners outside of the federal government can collaborate and share the results of a jointly conducted research and development project.

Strategic Partnership Projects or Non-Federal Entity Agreements

In a Strategic Partnership Project (SPP) or Non-Federal Entity agreement, Sandia can perform work on a reimbursable basis for a non-federal entity from private industry, state or local governments, nonprofits, or academia.

New Mexico Small Business Assistance Program

The New Mexico Small Business Agreement (NMSBA) Program allows New Mexico small businesses facing a technical challenge to access the unique expertise and capabilities of Sandia.

Technology Deployment Center Agreements

Technology Deployment Centers (TDCs) are a unique set of scientific research capabilities and resources. TDCs are intended to satisfy DOE programmatic needs while remaining accessible to outside users.

Sandia partnerships bring cutting-edge technologies to the marketplace and contribute to the economic well-being of the nation.

Learn more about Sandia's impact

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Sandia National Laboratories
P.O. Box 5800
Mail Stop 0114
Albuquerque, NM 87185-0114

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