Center for Materials Processing
2020 Annual Report

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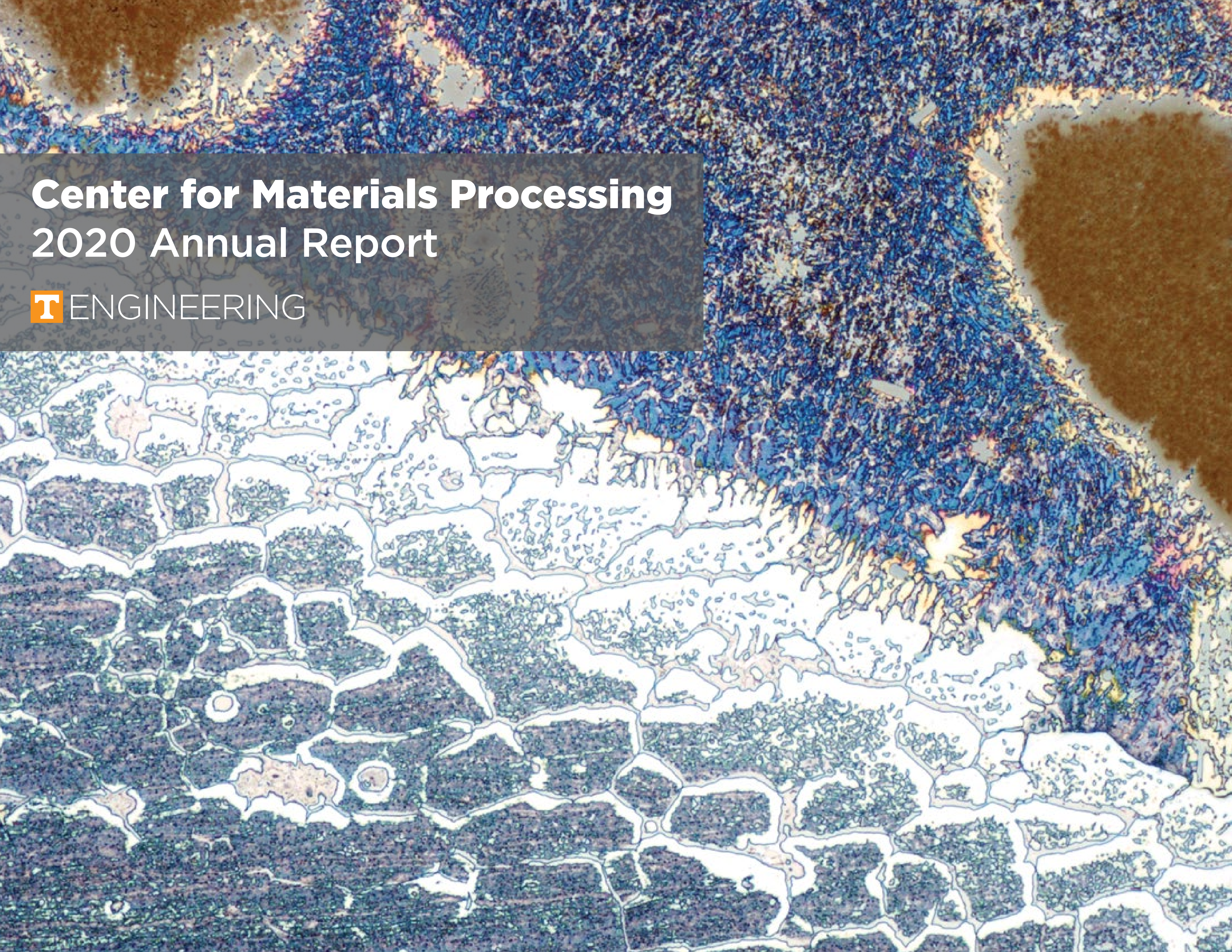

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Designer / Mitchell Williamson • Project Manager / Melissa Callahan

On the Cover: Jason Bohling, Optical light micrograph of base metal, heat-affected zone (HAZ), and fusion zone (FZ) of a resistance spot weld in 5754 aluminum alloy, as part of a dissimilar spot weld between aluminum and steel. The base metal and HAZ are visible in the lower left portion of the micrograph, and the FZ is located in the upper right portion of the micrograph. The fusion line, separating the HAZ and FZ, bisects the image from top-left to lower-right. In the HAZ, partial dissolution of the base metal precipitates, due to the resistance welding thermal cycle, is observable as white precipitate-free regions. The color variations in the micrograph are indicative of differences in chemical composition. Color etch with Weck's reagent. Original magnification 500X.

Advisory Committee

Established in early 2014, the CMP Advisory Committee works with the CMP Director Claudia Rawn and Associate Director for Industrial Partnerships and Undergraduate Research Chris Wetteland regarding various areas of research CMP can advocate for and invest in for the future. The CMP leadership and the Advisory Committee are working together with the goal of bringing positive recognition to CMP, the Tickle College of Engineering, and the University of Tennessee in areas related to materials processing. In early August 2019, the CMP Advisory Committee met to begin discussing how CMP can help provide a link between local industry and the University of Tennessee.

- **Sudarsanam Suresh Babu**, PhD
  UT-ORNL Governor's Chair for Advanced Manufacturing, Department of Mechanical, Aerospace, and Biomedical Engineering
  Tickle College of Engineering
  University of Tennessee, Knoxville
- **William Dunne**, PhD
  Associate Dean for Research and Facilities
  Tickle College of Engineering
  University of Tennessee, Knoxville
- **Neal Evans**, PhD
  Local Industrial Consultant
- **Veerle Keppens**, PhD
  Chancellor's Professor and Head, Department of Materials Science and Engineering
  Tickle College of Engineering
  University of Tennessee, Knoxville
- **Beth Matlock**
  Senior Materials Engineer
  Technology for Energy Corporation (TEC)
- **Danny Norman**
  Center for Industrial Services
  University of Tennessee
- **William Peter**, PhD
  Director, Manufacturing Demonstration Facility
  Oak Ridge National Laboratory
- **Trevor Toll**
  Research Engineering
  Analysis and Measurement Services (AMS) Corporation

Mission Statement

The Center for Materials Processing (CMP) supports teaching and conducting basic and applied research emphasizing relationships between processing, structure on various scales, and properties of all classes of materials. This support improves existing processing and synthesis techniques, helps develop new materials and technologies, aids the transfer of improvements to the applied sector, and equips students to thrive in the broad field of materials science and engineering. CMP fosters interdisciplinary activities and establishes partnerships with industries and other institutions as appropriate.

Executive Summary

CMP works as an advocate in the field of materials processing at many levels, including recruiting outstanding undergraduate and graduate students, advancing research, and engagement in materials processing-related fields. Current areas of specific interest include advanced manufacturing, materials characterization, crystal growth, scintillation detectors, nuclear materials, and energy-related materials.

An important component of CMP's mission is transferring research outcomes to industry and supporting industry partners and collaborators. To address technology transfer, CMP offers industrial memberships, where membership funds can be used to support students and/or access to facilities. Through these memberships, students gain valuable academic and industry experience while companies improve their competitive advantages by gaining access to a variety of research equipment. Serving the Tennessee community through industrial relationships has been a top priority for CMP in 2019–2020 and will continue to be in the coming years.

CMP either partially or fully supports both graduate and undergraduate student assistantships through stipends. To help these students advance their processing research projects, CMP also provides support for time on state-of-the-art instruments including electron microscopes and laboratory X-ray diffractometers. CMP also maintains key pieces of processing equipment for CMP-supported students and industrial members to use. Lastly, CMP annually sponsors several competitive poster sessions with both faculty and outside representatives serving as judges. The student winners are provided travel support to present their research externally and represent UT at conferences.

CMP Staff

Claudia Rawn
Director

Claudia Rawn has been director of CMP since 2012. She is an associate professor in the Department of Materials Science and Engineering (MSE) at the University of Tennessee (UT) and has taught Introduction to Materials Science and Engineering, X-ray Diffraction and Structural Characterization of Materials, and Principles of Ceramics, and is one of the original faculty associated with the Materials Processing course that was first introduced to MSE in 2005. Rawn has served as chair of the MSE Undergraduate Affairs Committee, the Materials Advantage faculty advisor, and is on the UT Undergraduate Research Advisory Committee. Her research interests include investigations of crystal structures, phase transitions, and thermophysical properties of a variety of materials using in-situ X-ray and neutron scattering methods. Rawn is the PI and site director of the UT site of the Manufacturing and Materials Joining Innovation Center (Ma2JIC), funded by the National Science Foundation (NSF) Division of Industrial Innovations and Partnerships (IIP) and individual industrial memberships. She received her bachelor's in materials engineering from Virginia Polytechnic Institute and State University, her master's in chemistry from George Mason University, and her doctorate in materials science and engineering from the University of Arizona.

Chris Wetteland
Associate Director of Industrial Relationships and Undergraduate Research

Chris Wetteland has been the associate director for industrial relations and undergraduate research since 2017. Wetteland is an associate professor of practice in MSE at UT where he teaches laboratory coursework and senior design. His research interests include radiation damage in nuclear materials, ceramic processing, solar energy, ion beam analysis, advanced manufacturing, early solar system processes, and STEM outreach. He received his bachelor's in geology from Northeastern Illinois University, his master's in ceramics and materials engineering from Rutgers, and his doctorate in earth and planetary sciences from UT. Wetteland previously worked at Los Alamos National Laboratory as a staff member from 1997–2006, where his primary research was in ion beam analysis and radiation damage in materials. From 2010–2013, he was a research fellow at the University of Wisconsin-Madison, where he investigated accelerated aging of nuclear materials using particle accelerators.

Amber White
Administrative Specialist

Amber White has served as the administrative specialist for CMP since 2016. Before joining UT, she spent five years in the social work sector, specializing in low-income senior housing and fair housing regulation.

Karen Boyce
Financial Specialist

Karen Boyce is the financial specialist for CMP. She has been working within various university systems since 1995 and joined UT in 2011.

Gerald Egeland
Student Supervisor

Gerald Egeland is the CMP student supervisor and works with the undergraduate students on CMP Industrial Membership sponsored research. He has a joint appointment with MSE, serving as the undergraduate laboratory manager and the departmental safety officer. Egeland graduated with his bachelor's in materials science and engineering in 1997, his master's in 2000, and his doctorate in materials science in 2005 from New Mexico Institute of Mining and Technology. His graduate work focused on biomimetic materials, carbon nanotubes, nuclear-fuel and radiation damage characterization and was performed at Los Alamos National Laboratory. After obtaining his doctoral degree, he was a postdoctoral research associate at the Paul Scherrer Institute in Switzerland before transferring to Idaho National Lab, and eventually the University Nevada, Las Vegas (UNLV). His personal research has included working on radiation damage of alloys, ceramic powder processing for advanced fuel, and fuel-cladding interactions. Over the years in his various capacities, Egeland has supervised students and technicians and began teaching while at UNLV, producing and teaching a graduate SEM course. He also taught chemistry part time at both Nevada State College and the College of Southern Nevada.

Forging Ahead

By Meghan McDonald.

Founded by a University of Tennessee meteorologist in 1902, Fulton is now a world-leading producer of seamless bellows. Over the past year, this company has forged a partnership with the CMP that reconnects them with their history and creates new opportunities in a business centered on an ancient technology.

Greg Canada joined Fulton Bellows as vice president and general manager last year, shortly after the partnership became official.

"I wish I could take credit for it," he said. "The goal is to leverage our combined strengths. We provide real-life industrial exposure to these students. They look at this old type of technology—bellows—and evaluate our processes with incredibly high-tech equipment."

Fulton faces an industry-wide challenge: new products are rarely designed with old technologies. And in the verticals Fulton serves, like aerospace, automotive, and oil and gas, there are always new products being introduced.

In the spring of 2019, Fulton was acquired by Smiths Group plc, which set about investing in new equipment and improving safety and quality standards. Canada has been tasked with "forging new territories" in which Fulton can compete outside of their traditional bellows market.

Last year, Fulton hosted a student for the first time through their CMP partnership. This academic year, Manufacturing Engineer Manager Kelly Ferguson will be more involved in directing the projects Fulton assigns to students.

"Students bring fresh new ideas to the table that we may not see. They're exposed to newer technologies. I think there's a good future for this program here," Ferguson said.

Fulton and CMP have established a cadence of communication that gives the company confidence in the partnership. Fulton creates a project or "wish list" to help professors understand what they need to accomplish. They get frequent updates from their primary contact, Assistant Professor Eric Lass.

"We have access to the students, and then [Lass] also rolls up his sleeves and gets involved," Canada said.

Both Canada and Ferguson are excited to see how the partnership will grow year after year.

"They stay very in step with what we're trying to do. We've discovered a lasting partnership," Canada said.

Ferguson, speaking from his role of "getting the company to the next level," looks ahead to the potential for hiring new talent.

After only one year, it's clear that the CMP partnership is a perfect fit for Fulton's push toward the future.

"We're bringing together an ancient force and a brand-new force," Canada said. "This is where they collide. This is how we become a better business."

Problem Solving Power

By Meghan McDonald.

The Center for Industrial Services (CIS) specializes in problem solving for small to medium, locally-owned and operated manufacturing companies. As part of the UT system and a member of the nationwide Manufacturing Extension Partnership, CIS is always looking for new resources within these networks to help them serve their clients. In 2019, George Aslinger, Bill Hicks, and other CIS solutions consultants toured the CMP facility. They immediately recognized the potential.

"Partnering with CMP," Hicks said, "has given us a new and powerful problem-solving tool to bring to our clients."

In their roles at CIS, Hicks and Aslinger match manufacturers with resources that fit their specific business problems. All CIS solutions consultants have real-world manufacturing experience.

"We're practitioners, not an academic unit," Hicks said. "We understand the pain our clients feel when they can't get the resources they need."

CIS clients typically employ 500 people or fewer and lack the funding to access cutting-edge equipment and facilities.

"When we toured the CMP facility and saw the capabilities there," Aslinger said, "I got excited about the opportunities to help manufacturers I work with answer questions they struggle with. Through CMP, we can provide our clients access to millions of dollars' worth of equipment, like the state-of-the-art scanning electron microscope."

Both Aslinger and Hicks have connected client companies with CMP over the past year. For example, in East Tennessee, Hicks is working with an aluminum anodizing company to figure out why certain bolts keep breaking. CMP's scanning electron microscope is helping diagnose the issue. In the Chattanooga area, a food packaging maker came to CIS for help after an auditor asked something new: do traces of ink transfer from the non-food side to the food side? Again, Aslinger turned to CMP as the right resource for the job. The CMP team developed test methods to discover the answer. This company, which signed a CMP facilities management agreement, now regularly sends samples to test.

"Having a tool like CMP that is reasonable in cost opens doors we couldn't open otherwise," Aslinger said. The affordable price of the entry-level CMP facilities management agreement is a deal-maker for CIS clients, who must keep a close watch on their budgets. CIS is sensitive to its clients' economic needs and seeks to provide only solutions that help those companies save money, increase sales, or otherwise benefit economically. Other resources similar to CMP remain very expensive for these manufacturers.

CIS clients are also concerned about the talent pipeline.

"Eighty percent of the companies we serve are looking for talent," Aslinger said. "They wonder what the university is doing to help them and develop that talent." CMP directly fills that need by hiring students to research the questions that manufacturing companies are asking. The hands-on work introduces students to the many opportunities in the industry—and prepares them to become the next generation of Tennessee manufacturers.

CMP Supported and Associated Graduate Students

In the last year, CMP has supported twelve graduate students, the majority of whom received funding through its competitive application process. These students, along with students supported by industrial memberships and contracts affiliated with CMP, are featured here.

John Bohling

John Bohling earned both his bachelor's and master's degrees in material science from UT and is currently a PhD candidate working with the Materials Joining Group (MJG) under the direction of Professor Emeritus Carl Lundin.

The focus of Bohling's research has centered around microstructural changes and properties that occur in metals as a result of welding and heat treatment, primarily focusing on nickel-based alloys and low-alloy steels. The choice of welding process, specific welding parameters, and heat treatment conditions can dramatically alter properties such as strength, toughness, creep performance and corrosion resistance of industrial steels.

Bohling's research has concentrated on understanding the relationship between processing and resulting properties for the successful fabrication of steel structures and prevention or mitigation of welding-related problems. The Cr-Mo steels that he has primarily focused on are widely used in the power generation and petrochemical industries (for steam piping in power plants and oil refineries, for example).

In welded Cr-Mo steel steam piping, the high temperature conditions lead to creep void formation in specific regions such as the coarse and fine-grain regions of the base metal weld heat-affected zone (HAZ) or the weld deposit, which can eventually result in premature failure.

Understanding how creep damage occurs in Cr-Mo steel weldments is important for determining when existing steam piping must be repaired or replaced and also for developing Cr-Mo steels with improved creep properties that enable power plants to operate at higher temperatures for obtaining higher efficiencies and longer service life.

Bohling has been involved in specific projects including microstructural characterization of creep-damaged, submerged-arc weldments in Cr-Mo-Vsteels for steam piping, weldability investigations of high entropy alloys (HEAs) such as AlxCoCrFeNi, and high temperature hydrogen attack of carbon and low alloy steels. He has performed failure analysis of 20Cr-32Ni-1Nb heat-resistant cast austenitic stainless steel used for outlet headers and manifolds in hydrogen reforming furnaces.

In collaboration with industry, Bohling uses specialized microstructural simulation equipment (Gleeble) for hot ductility testing together with microstructural characterization to evaluate the HAZ liquation cracking susceptibility of high alloy and high temperature materials.

Bohling has also served MSE as a teaching assistant in several key undergraduate classes including welding metallurgy, materials processing, materials selection in design, and materials selection. Bohling has also been recognized with both the MSE Graduate Student Award for Excellence in Service and Excellence in Teaching.

Lundin has noted that, no matter how busy Bohling is on his own projects, he has never refused to assist his fellow students in MSE and those students of other engineering departments in solving or measuring material performance for their master's and doctoral projects.

Bernadette Cladek

What is your thesis topic?

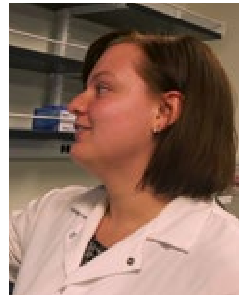
Investigation of CH4-CO2 hydrate structure and dynamics with neutron scattering experiments and complementary simulations.

How is materials processing involved in your research?

I assembled a hydrate-synthesis lab, which is included in the JIAM ceramics laboratory, to synthesize gas hydrate powders at the required high pressure and low temperature conditions with CH4 and CO2 to be studied with neutron scattering.

Provide an example of where the material, process, or properties you are studying might find an application.

I synthesize CH4, CO2, and mixed CH4-CO2 hydrates to perform structural studies with in situ total neutron scattering and dynamic studies with inelastic neutron scattering experiments. I use complimentary classical molecular dynamics simulations and density functional theory of these systems to complement neutron data analysis. These structural and thermodynamic studies will provide a comprehensive understanding of CO2-CH4 solid solutions, exchange kinetics, and implications on hydrate structure to better inform the production of CH4 from natural hydrate deposits via CH4-CO2 exchange.



Kate Higgins

What is your thesis topic?

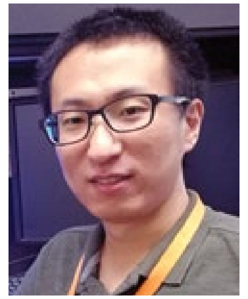
Utilization of automated synthesis and machine learning for the exploration of hybrid organic-inorganic perovskite combinatorial libraries.

How is materials processing involved in your research?

To create combinatorial libraries of various hybrid organic-inorganic perovskite systems, I utilize a robotic pipetting robot, commonly used in the biological field, to make microcrystals. This requires taking into consideration certain aspects, such as solvents, antisolvents, and fabrication methods.

Provide an example of where the material, process, or properties you are studying might find an application.

Hybrid organic-inorganic perovskites have emerged as a promising candidate for solar cell applications. However, the stability of these materials under illumination and in ambient conditions remains elusive. In this project, I am first determining the optimal compositions for this application based on their optoelectronic properties. Further, I am developing a method to measure the change in these optoelectronic properties over time in ambient conditions. From this, I will be able to determine which hybrid organic-inorganic perovskites have the best intrinsic stability.



Yongtao Liu

What is your thesis topic?

The focus of my research is to explore ion migration and ferroic behavior in metal halide perovskites (MHPs), as well as understand their effects on the optoelectronic properties of MHPs.

How is materials processing involved in your research?

I use solution-processed polycrystalline metal halide perovskites (MHPs) in my research. In order to synthesize MHP samples with desired properties, I adjust precursor solvent, substrate, and thermal annealing temperature to control the nucleation and the crystallization of polycrystalline MHPs. In addition, numerous sample cleaning methods are also often used before characterizing MHPs' properties to suppress fake signals induced by contamination.

Provide an example of where the material, process, or properties you are studying might find an application.

Despite the impressive photovoltaic performance delivered by MHPs in the past decade, poor stability of MHPs hinders the practical applications of MHPs solar cells. My research on understanding the effects of ion migration on optoelectronic properties of MHPs will be useful for improving the stability of MHPs solar cells.

CMP Supported and Associated Graduate Students

Robert Minneci

What is your thesis topic?

My thesis topic is on characterizing a high temperature copper alloy called GRCop-84 that NASA is developing for use in its future space craft with additive manufacturing. My efforts are focused on adding to the characterization efforts that NASA has already done by using neutron diffraction techniques to learn information unobtainable otherwise.

How is materials processing involved in your research?

Materials processing is the core of my research. GRCop-84 would not be a viable aerospace alloy without the unique processing advantages provided by additive manufacturing. GRCop-84's thermal and mechanical properties are some of the best available, but its high material and machining costs have limited its use outside of NASA. From a processing perspective of properties and cost, additive is the best possible choice for this alloy, but there are numerous microstructure-property relationships that require evaluation. Through metallography and neutron diffraction, I am investigating the development of thermal residual stress, evolution of the microstructure from powder to final part, and mechanical load sharing between the phases; all of which are directly correlated to processing.

Provide an example of where the material, process, or properties you are studying might find an application.

GRCop-84 has excellent high temperature properties and is best served in applications as a heat conductor and structural component. NASA is developing it for the combustion chamber liners of rockets, but it can be applied to welding equipment, reactor walls, aerospace hardware and other similar high heat flux applications.

Brianna Musico

What is your thesis topic?

I am performing a study on the synthesis and characterization of a series of multi-component high entropy oxide samples with spinel, perovskite, and garnet crystal structures.

How is materials processing involved in your research?

My research is dependent on materials processing as it is based around sample creation via both the solid-state synthesis method and polymeric steric entrapment synthesis. As my work focuses on the synthesis and characterization of these multicomponent ceramics, termed high-entropy oxides, a lot of time is spent in the processing step. Combining 5 or more elemental oxides to try to achieve single phase formation and investigating how the properties (electronic/magnetic/structural) change with substitutions in the composition makes for quite the expansive and interesting research project.

Provide an example of where the material, process, or properties you are studying might find an application.

I am on the basic science side of things in my current stage of research for this new class of materials, so the applications of many of the materials I work with are yet to be determined. The goal is to work towards engineering new ceramic materials by applying the concept of entropy stabilization to complex oxides with hopes to achieve and have the ability to tailor improved mechanical properties, superconductivity, and magnetic switching temperatures among the many other possibilities this class of materials has to potentially offer.

Grace Pakeltis

What is your thesis topic?

I am studying the plasmonic and phononic phenomena in 2d and 3d nanostructures through high resolution electron energy loss spectroscopy.

How is materials processing involved in your research?

At the center of my research is a dedication to the advancement of materials processing through micro- and nanofabrication techniques. The investigation of fundamental plasmonic phenomena is advanced by improvements in micro- and nano- 3d manufacturing. I utilize a hybrid fabrication approach combining focused electron beam induced deposition, atomic layer deposition, and sputtering to create a direct write method for 3D plasmonic structures. The development of this material's processing technique creates a path towards robust geometric studies to elucidate plasmonic property trends.

Provide an example of where the material, process, or properties you are studying might find an application.

The field of plasmonics exploits the unique property of metallic nanostructures to manipulate light at the nanometer scale. The efficiency in which plasmonic nanostructures couple light into intense optical near-fields has a variety of applications across multiple fields (e.g., sensing, imaging, photovoltaics, and photocatalysis.)

Brandon Shaver

What is your thesis topic?

My dissertation is focused on evaluating the electrical properties of uranium dioxide as a candidate material for solid-state direct-conversion neutron detectors. Dopant materials have been studied in ion-implanted single crystal samples that have been subjected to neutron irradiation. Cerium dioxide has also been used as a non-radioactive surrogate to safely study material processing methods of improving electrical properties.

How is materials processing involved in your research?

Uranium dioxide does not inherently meet the electrical properties necessary to effectively function as a semiconducting material in a solid-state neutron detector. Materials processing methods to incorporate dopant materials is critical to this research. Carefully selected dopant materials can directly impact the microstructure and electrical properties.

Provide an example of where the material, process, or properties you are studying might find an application.

While there are several challenges beyond optimizing the electrical properties of uranium dioxide that must also be addressed, a solid-state neutron detector based on this material could offer the potential for the development of devices with incredibly high detection efficiencies.

Tyler Smith

What is your thesis topic?

"Exploring Structural and Electronic Properties of Triangular Adatom Layers on the Silicon Surface Through Adsorbate Doping"

How is materials processing involved in your research?

The research is primarily focused on adsorbate doping of correlated electronic systems on silicon platforms, potentially driving these surfaces into a superconductive state. This is performed in-situ, where these surfaces are decorated with electron-donating alkalides or electron-accepting molecules.

Provide an example of where the material, process, or properties you are studying might find an application.

The possibility of attaining superconductivity on a silicon platform is highly lucrative as it is an abundant material in modern devices, with a potential application into new technologies such as quantum computing.

Maiosheng Wang

What is your thesis topic?

My thesis topic focuses on the spin effects of excited states in organic semiconductors and organic-inorganic hybrid perovskite materials.

How is materials processing involved in your research?

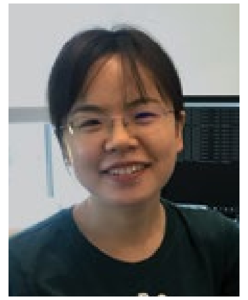
The high-quality materials/devices are the foundation of my research. I prepare organic and perovskite thin films, heterojunctions, and optoelectronic devices through solution spin-cast and thermal evaporation methods. Then I will use magneto-optical measurements and ultrafast laser spectroscopy to investigate the key process of the excited states to have better understanding of the optoelectronic working principle in these material systems.

Provide an example of where the material, process, or properties you are studying might find an application.

The spin effects of excited states in organic semiconductors and perovskite materials can be used for next-generation spintronic and spin-related optoelectronic applications through the active manipulation of spin degrees of freedom. These devices can significantly reduce the power consumption and increase the memory and processing capabilities.

> **"[Maiosheng] has been working on materials processing for organic electronics used in renewable-energy, sensing, and lasing applications. Based on the support from CMP, he has authored and co-authored 18 research articles, published in high-impact journals. He has also received a scholarship from the US Air Force to present his work."**
>
> —Bin Hu, MSE Professor

CMP Supported and Associated Graduate Students



Xue Wang

What is your thesis topic?

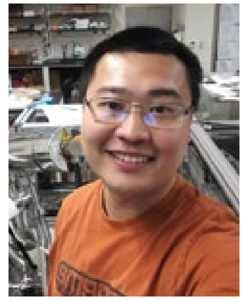
My thesis topic is on predictive micromechanical modeling of processing behavior in advanced materials joining techniques. My efforts are focusing on investigating the tool workpiece stick-slip condition in the friction stir welding process and providing analytical and computational mechanics models to describe the solid-state bonding in severe thermomechanical processes.

How is materials processing involved in your research?

Friction stir welding is a quintessential solid-state-bonding technology in which the workpieces at the bonding interface are not melted in spite of significant heating. When compared with traditional fusion welding, friction stir welding shows several superiorities and has been widely used to join low melting temperature material, such as Al alloys. For my study, the main objective is to quantify the novel material processing technique friction stir welding through an integrated computational material engineering (ICME) approach.

Provide an example of where the material, process, or properties you are studying might find an application.

Friction stir welding has been applied in many fields, such as aerospace, automotive and railways. The structure integrity of the weldment mainly depends on the solid-state bonding condition at workpiece interface, which is controlled by processing parameters. Numerical simulation could help to get a better understanding of the dependence of bonding evolution on processing parameters and materials behavior, which will help to reveal design strategies in promoting the quality of the weldment.



Junyi Yang

What is your thesis topic?

My dissertation title is "Many body physics in pseudospin-1/2 iridate." Theoretical attempts to solve any many body problem are often limited by the computational capability; thus, experimental study of representative materials becomes necessary. A systems like iridate, which combines electron correlation and spin orbit coupling, is a rare S-1/2 square lattice system for studying many body physics described by Hubbard Hamiltonian. This study will provide us a better understanding of the fundamental science; additionally, it could open new possibilities for realization of exotic phenomenon like high temperature superconductor.

How is materials processing involved in your research?

The realization of pseudospin-1/2 iridate systems requires state-of-the-art synthesis methods, and advanced characterization techniques are necessary to understand its properties. The key concept in the 5d transition metal oxides is the strong interplay between charge, spin and structural degrees of freedom. The bulk single crystal iridate is often too robust, while iridate heterostructures achieved by atomically layer-by-layer growth technique provide a much higher tunability. The structural degree of freedom by applying epitaxial strain on the iridate heterostructure, which is achieved by synthesizing iridate on various substrates with different lattice mismatch, can be used to tune the strength of the electron correlation. Through measurements like X-ray diffraction, one can accurately know the structural distortion and deformation induced by epitaxial strain. Combined with the measurements of electronic and magnetic properties, we are able to understand the electron interaction under different correlation limit.

Provide an example of where the material, process, or properties you are studying might find an application.

The development of semiconductors has become more and more difficult to keep up with Moore's law; thus, much attention is turned to alternative electronic devices like spintronics. The iridate superlattices can also be made into antiferromagnetic spintronics. Through an atomically controlled layer-by-layer growth technique, we are able to make an iridate superlattice that approaches quasi-2D limit. By applying an external magnetic field on the iridate superlattice, one is able to control the strength of magnetization and ordering temperature. This can be used as a switch where the on and off of magnetic ordering is controlled by an external magnetic field.

> **"[Junyi] is the best graduate student in my group, making great impacts to our research far beyond his own project, including maintenance of our growth system during this difficult time."**
>
> —Jian Liu, Assistant Professor
> Department of Physics and Astronomy

Thesis/Dissertation Titles

Amanda Haglund

PhD, Summer 2019

Dissertation: "Thermal Conductivity of MXY_3 Layered Magnetic Semiconductors"

Advisor: David Mandrus

Anna Hoffman

PhD, Summer 2019

Dissertation: "Correlating the Effects of Aging and Oxygen Plasma Treatment to the Electrical Properties of WSe_2 and $PdSe_2$"

Advisor: Philip Rack

Current Position & Employer: Postdoctoral Research Associate, Y-12 National Security Complex/University of Tennessee

Matt Loyd

PhD, Summer 2019

Dissertation: "Investigation of Environmental Degradation of Plastic Scintillators"

Advisor: Mariya Zhuravleva

Current Employer: Y-12 National Security Complex

Camera Foster

PhD, Fall 2019

Dissertation: "Czochralski Growth and Scintillation Properties of Li, Na, and K Co-doped $(Lu_{0.75},Y_{0.25})_3Al_5O_{12}$ Single Crystals for Applications in Medical Imaging"

Advisor: Charles Melcher

Current Employer: National Nuclear Security Administration (Washington, D.C.)

Chanho Lee

PhD, Fall 2019

Dissertation: "Design and Development of Strong and Ductile Single BCC Refractory High-entropy Alloys for High-Temperature Applications"

Advisor: Peter Liaw

Current Position & Employer: Directors Funded Postdoc, Los Alamos National Laboratory (Los Alamos, N. Mex.)

Ling Wang

PhD, Fall 2019

Dissertation: "Phase Stability of Precipitates After Ion Irradiation and Creep Deformation"

Advisor: Steven Zinkle

Current Position & Employer: Postdoctoral Research Associate, Oak Ridge National Laboratory

Christine Ajinjeru

PhD, Spring 2020

Dissertation: "Rheological Evaluation and Printability Guidelines of High-Performance Amorphous Thermoplastics and Carbon-Fiber Reinforced Composites for Additive Manufacturing"

Advisor: Chad Duty

Current Employer: Deloitte

Sabrina McCoy

MS, Spring 2020

Thesis: "Synthesis and Structural Characterization of $Ca_{12}Ga_{14}O_{33}$"

Advisor: Claudia Rawn

Current Employer: BWXT (Lynchburgh, Va.)

Youxiong Ye

PhD, Spring 2020

Dissertation: "Mechanical Behavior of Body-Centered Cubic High-Entropy Alloys"

Advisor: T.G. Nieh

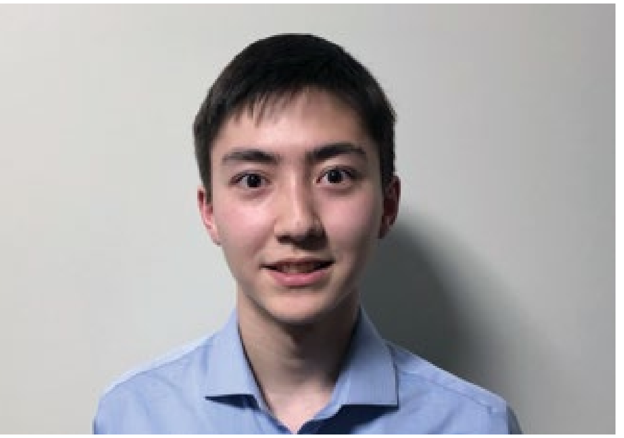
Current Position & Employer: Postdoctoral Research Associate, Dartmouth College (Hanover, N.H.)

Undergraduate Research Spotlight

Jared Floyd

Jared Floyd graduated in May with a bachelor's degree in materials science and engineering. Floyd was born in Mt. Pleasant, North Carolina, where he became an Eagle Scout at thirteen and participated in his high school marching and symphonic band. After September 11, Floyd enlisted into the United States Air Force and upon graduating high school, he toured the country with a Division One Drum and Bugle Corps for three months. He then attended basic training in San Antonio, Texas, and his first duty assignment was at Pope Air Force Base in North Carolina. After seven years, he deployed to Bagram Air Base in Afghanistan as part of Operation Enduring Freedom.

Floyd was reassigned to Shaw Air Force Base in South Carolina in early 2013. He also deployed to Osan Air Base in South Korea for six months. In September 2014, Jared received an honorable discharge and returned to North Carolina to study at UNC at Charlotte before transferring to UT. During his time as an undergrad, Floyd participated in research through an NSF veteran's research supplement and was supported by CMP. He quickly became an expert at running the hot isostatic press for consolidating materials. Floyd is currently working as an engineer at Amentum in Oak Ridge.



Cale Overstreet

Cale Overstreet is a junior studying nuclear engineering and conducting research under Associate Professor Maik Lang. Currently, Overstreet is researching the local structure of Dy_2TiO_5, a durable ceramic used in nuclear control rods due to its resistance to radiation and high temperatures.

In the lab, he thoroughly enjoys using different analytical techniques such as X-ray diffraction, neutron scattering, and Raman spectroscopy. Each characterization tool provides complementary information about the structure.

Overstreet uses the data he gathers to further the understanding of the factors that drive phase equilibrium as it is vital for predicting the behavior of rare-earth titanates.

He has made poster presentations at EUReCA and at the ASM Oak Ridge Chapter student night. In the future, Overstreet plans to continue his research with Lang while completing his degree and then attend graduate school and continue to study complex oxides.

Nicholas Legaux

Nick Legaux is studying chemical engineering and conducting research with Associate Professor Brian Long. Prior to studying at UT, Legaux began teaching himself organic chemistry through textbooks and scientific journals, which caught the eye of Long.

After arriving on Rocky Top, Legaux began working with Long on catalytic activity of ring opening metathesis polymerization of lactide, which may prove useful for preparing certain polymers in the future.

While Legaux has proven he is adept at researching information for a project, he also enjoys working in the lab and creating the catalysts. His aptitude to understand complex concepts led him to authoring a manuscript on catalytic activity of ring opening metathesis polymerization of lactide in *Catalysis Science and Technology*.

Beyond work with Long, Legaux is also working with UT-ORNL Governor's Chair for Advanced and Nanostructured Materials Rigoberto Advincula on developing resins for stereolithography 3D printing, which have applications in medical devices.

After graduation, Legaux plans to pursue a PhD in chemistry with a focus on either polymer and/or chemical synthesis.

Undergraduate CMP/MSE Scholarship Recipients: Madeline Loveday, Jackson Spurling, Samantha Maness, and Melanie Moczaldo.

Three Goldwater Scholars Awarded to Engineering Vols

By Randall Brown.

Earlier this year, Engineering Vols Samantha Maness, Jackson Spurling, and Logan White were named 2020 Goldwater Scholars, earning the most prestigious undergraduate STEM scholarship awarded in the United States.

Samantha Maness describes the award as an incredible feeling of recognition for her hard work in class and in research.

"It really drives home to me the fact that the work I'm involved in matters outside of my immediate academic sphere," she said. "The experience of applying for this award not only bolstered my future ability to advocate for myself to graduate schools, but it also gave me confidence that I will be a genuinely competitive candidate for these programs."

Maness's scholarship-worthy research has been toward developing and studying new functional composite materials for use in additive manufacturing.

While Maness works in materials, her faculty mentor is Brett Compton, an assistant professor in MABE. She has worked in his advanced manufacturing research group since her first year at UT.

After graduation, Maness plans to pursue a PhD in materials science with the ultimate goal of becoming a university professor and continue her work in the development of novel functional composite materials and additive manufacturing science.

Jackson Spurling earned recognition for research on advanced characterization of materials, with a focus on energy applications.

"I leverage tools like electron microscopy to understand how the microstructure and, by extension, the properties, of materials change as a result of testing under conditions like high temperature or high stress," he explained.

Spurling appreciates encouragement from faculty mentors like Compton and Associate Professor Claudia Rawn, and he also cites welcome support from Lawrence Allard and Kinga Unocic at Oak Ridge National Laboratory and Wenyu Huang at Ames National Laboratory.

He feels a direct influence from these mentors on making him a better researcher and helping him reach his goals of earning his PhD and eventually conducting research in advanced materials for energy sustainability at a national laboratory or university.

Logan White's focus in MSE has been within the field of additive manufacturing.

"Specifically, I study the laser powder-bed fusion technique using high resolution synchrotron tomography and radiography," he said. "The goal is to develop a better understanding of this process so it may be incorporated into industrial applications."

White said the Goldwater Scholarship will help him further his research path and allow him to attend conferences that may have otherwise been out of his budget.

Associate Professor Hahn Choo has mentored and worked closely with White during the young researcher's undergraduate career, providing many opportunities and pushing him to fulfill his potential.

After graduation, White plans on seeking a PhD in materials science and eventually working in a national lab.

The Goldwater Scholarship Program was established by Congress in 1986 to honor US Senator Barry M. Goldwater.

Samantha Maness

Jackson Spurling

Logan White

Ready for What's New

By Meghan McDonald.

Assistant Professor Katharine Page wanted undergrad researchers in her joint UT-ORNL research group, so CMP Associate Director Chris Wetteland identified the right students for the job. Since late 2019, materials science majors Noah Sloan and Alexandria Carter have found their stride in the lab thanks to guidance from Page and Research Associate Palani Jothi.

Page's group "makes and explores new materials… promoting particular arrangements of atomic structure and enhancing specific physical properties."

Page handed over the reins of specific projects to Sloan and Carter, giving them a high degree of both responsibility and support.

"We're trying to train them to think like researching scientists early in their career," Page said, "not just give them a recipe to follow."

Sloan is studying the advantages and shortfalls of three different methods for synthesizing high entropy oxides.

"Generally, this is the first time anyone has attempted to synthesize these chemical combinations," said Sloan. "It's difficult to determine how we should tweak our techniques to produce our target samples."

Carter is focused on making nanoparticles with specific shapes and surfaces in order to change how they respond to electric fields. What excites her most is the moment of discovery each time she creates a new mixture in the autoclave.

"It could be different than what I intended to make," she said. "Usually I know based on color, temperature and what I've added if I'm getting close."

"It's great if they have exciting research results," Page said of both students. "But I'm focused on them enjoying the process of scientific discovery. It is training yourself to challenge your assumptions, try new things, and keep at it. The value of the whole process is what I want them to walk away with."

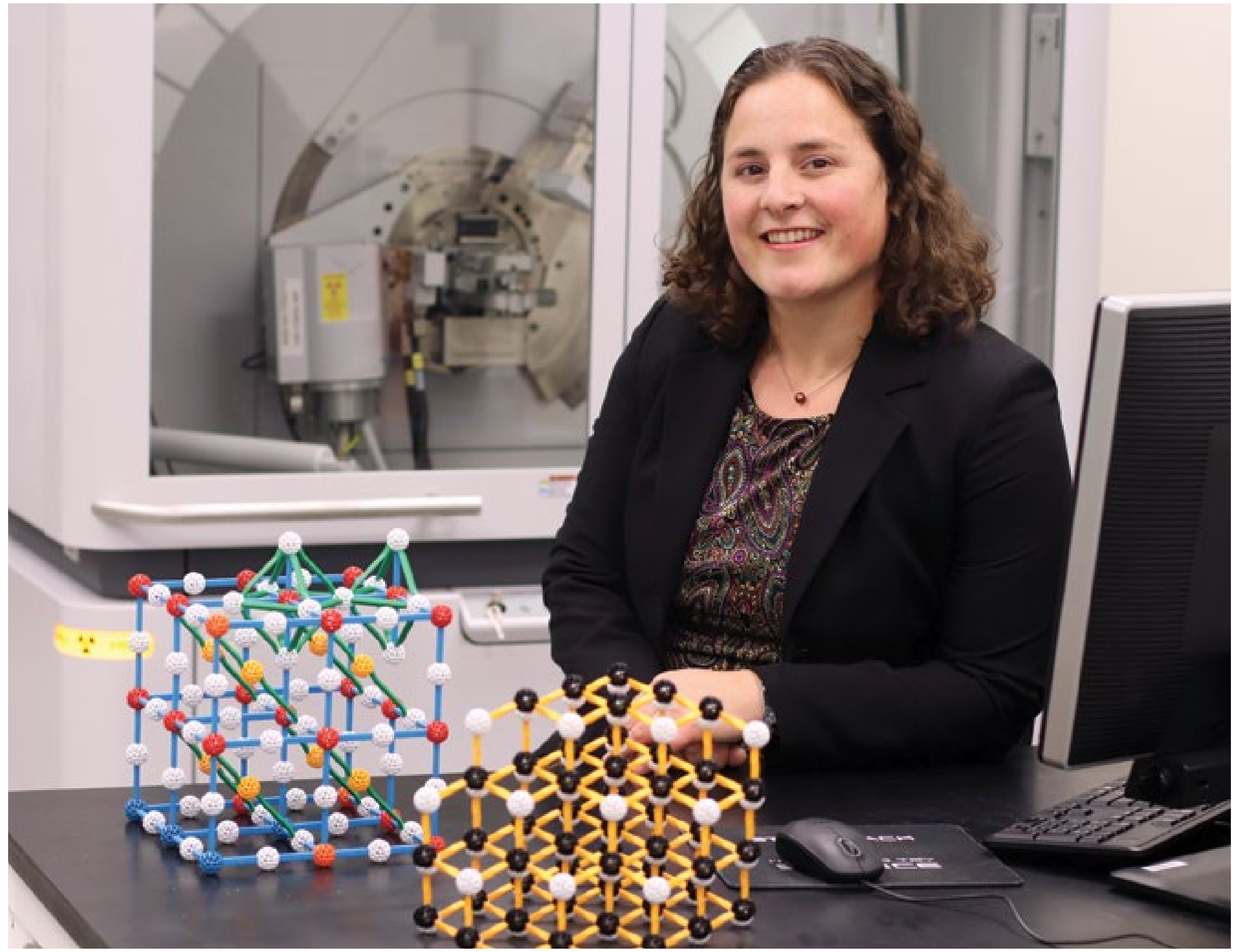
Page discovered her fascination with materials science and her love for the "research design and discovery loop" by participating in undergraduate research herself. She wants to provide her mentees with a similar experience—and share her connections in ORNL's Neutron Scattering Division.

"Knowing people from both UT and ORNL, and having this massive amount of knowledge surrounding me all the time, is a huge advantage," said Carter, whose goal this fall is to learn how to write a publishable paper. "I'm on the brink of finding something paper-worthy in my project," she said.

"When they started, they didn't have exposure to research," Jothi said. "Now, I can tell them how to make this compound in this way, and they have the experience to do that on their own."

"They were both open to seeing what research would be like," Page said. "They didn't have preconceived notions of how things should be done. They came in fresh and ready to learn."

Now, equipped with connections and experience, Sloan is one semester away from graduation. He aims to continue "refining skills I will need to become an excellent scientist and engineer when I enter the workforce."



Unlocking Potential

By Meghan McDonald.

"Crystals are everywhere," Assistant Professor Mariya Zhuravleva will tell you. "Look at your phone, your computer, your car."

When she joined the University of Tennessee in 2011, she brought with her a unique method for growing crystals. Her research into the development of new scintillator crystals holds promise for applications in medical imaging and national security—and for unlocking the potential of new researchers.

This fall, junior in materials science Madeline Loveday continues working in Zhuravleva's lab as an essential part of her research team.

Specifically, Loveday is helping Zhuravleva explore practical ways of creating high-entropy oxide crystals that effectively convert high-energy radiation into visible light. The composition of these materials is extremely complex, and their function is affected by many variables during synthesis.

"It's difficult to predict the desired properties using computational methods," Zhuravleva said. "Processing parameters are not part of the models." So her team must synthesize their own crystals in the lab.

Loveday plays a direct role in this. Over the past year, she has compared multiple synthesis methods while also studying the effects of the sintering atmosphere on crystal structure.

"This is very novel, so we have a lot of hypotheses we're testing," Zhuravleva said.

Loveday reiterates the potential of high-entropy oxides: "I like that there's enough literature out there to inform my research, but also there are so many projects that haven't been done yet."

Loveday began working with Zhuravleva in the summer of 2019, when she had only two semesters of college under her belt. Hands-on training in the lab, plus plenty of Zoom discussions due to COVID-19, has given her a tremendous learning opportunity that a classroom alone simply can't provide.

Last fall, Loveday attended the Materials Science & Technology conference in Portland, Oregon, where she presented a poster on sintering atmospheres and crystal structure.

"It was the most exciting part of my college experience so far," said Loveday, who was also thrilled to be a vital part of two peer-reviewed papers led by graduate student Matheus Pianassola last spring.

"When you take advantage of one opportunity," Loveday said, "they start snowballing. You get to see and do even more things. I'm very grateful for opportunities CMP has given me—the job, the conference, for letting me experience these things."

Zhuravleva's well-deserved 2019 NSF Early CAREER Award funds half of Loveday's position, with CMP funding the rest.

"I'm fortunate to have this pipeline where CMP provides students to us and we work with them," Zhuravleva said. "There's a very high demand for experts in this field, but there are so few places where this type of training is given to students. During this project, I believe we will accomplish a lot, contribute to the scientific community, and give students all the skills and opportunities we can."

Program Overview and Accomplishments

By Claudia Rawn.

The technical accomplishments of CMP are attributed to the associated graduate students, undergraduate students, and faculty that the CMP supports. Support comes in a variety of ways, including graduate stipends, paid undergraduate research, undergraduate scholarships, funds for using state of the art instruments housed in core facilities, travel support for students, smaller-scale instrument purchases, and the cost sharing of larger-scale instruments.

As in past years, the majority of CMP funds go to directly supporting the stipends of graduate students, hourly wages for undergraduate students, and salary support for CMP administrative and technical activities. This year, however, the percentage of funds used to support equipment increased as carry over from previous years was pooled to replace the bench top scanning electron microscope, which is used by countless students during recruitment activities, academic laboratories, and sponsored research.

Chris Wetteland continued in his role as CMP associate director of industrial relationships and undergraduate research. His duties include working with representatives from the Center for Industrial Services (CIS) and other local industry partners, both securing new facilities-level industrial memberships and continuing previously established relationships.

In FY20, Gerald Egeland, jointly supported by CMP and MSE, came on board to help support Wetteland in overseeing CMP equipment and students that support research for these facilities-level memberships.

CMP supports industry through technical consultations, performing research/characterization in the areas of materials processing, and identifying student talent for full- and part-time research positions. Our current and new industry partners continue to leverage our advanced microscopy techniques, mechanical testing, and undergraduate student eagerness to participate in research opportunities.

CMP has also continued to support JIAM activities by providing partial support to Michael Koehler, the JIAM Diffraction (XRD) Facility laboratory manager. Koehler is in charge of day-to-day operations of the laboratory, which includes helping students and industry members in the collection and analysis of X-ray diffraction data. XRD is part of UT's Core Facilities program, which is intended to provide access to high-end instrumentation, technical support, and expert consultation to both users from across the university and external customers for a fee.

XRD served more than 80 individual users in departments across UT from the Tickle College of Engineering, College of Arts and Sciences, the Herbert College of Agriculture.

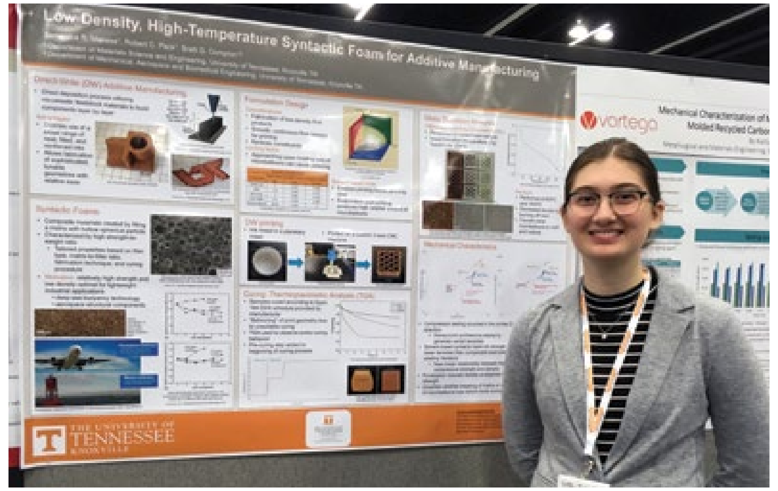
In FY20, CMP continued the competitive process for graduate students to be awarded support tied to distinct processing projects. Calls are issued in the fall and spring, and the students were asked to make oral presentations to the selection committee members for the first time, adding an additional layer of professional development to the process.

The students were also asked to include a budget and encouraged to request funds for partially supporting their stipend, core facility instrument charges, and for covering travel to a professional conference for reporting their results.

CMP-supported students were involved in a vast array of research topics, including binder jet additive manufacturing, preparation of scintillator materials, thinning of $PdSe_2$ flakes for field effect transistors, bulk metallic glasses, high entropy oxides, hybrid organic-inorganic perovskites for optoelectronic devices, metallic glass composites, modeling processing conditions of friction stir welding of light weight Al alloys, failure in welds, and failure mechanisms in Li-ion batteries.

Nine CMP-supported students graduated in FY20 and found employment in industry, academia, and federal government-related positions, including ORNL, Y-12, and the National Nuclear Security Administration in Washington, DC.

CMP-supported students also earned various accolades in FY20. Camera Foster was chosen as the student speaker at the fall 2019 graduate hooding ceremony. Samantha Maness, Jackson Spurling, and Logan White, MSE students who received partial support from CMP, were honored with Goldwater Scholarships. Bernadette Cladek, Ian Greeley,



Samantha Maness presents her poster at the M&T undergraduate poster competition in Portland/October 2019.

Chanho Lee, Collin Pekol, and Morgan Yount were all honored with receiving recognition from the chancellor for Extraordinary Professional Promise. CMP-supported undergraduates fared well at the Exhibition of Undergraduate Research and Creative Achievement (EUReCA) in April, with Kate Eikel, supervised by Professor Bin Hu, receiving first place and the team of Ryan Heldt and Logan White, supervised by Professor Hahn Choo, receiving third place in the engineering division. The winners then competed for recognition from the UT Office of Undergraduate Research (OUR), the event sponsor, with Eikel winning gold.

CMP awards full or partial travel support to students who have won local CMP-supported poster competitions, including one held in collaboration with the local chapters of the Oak Ridge Chapter of ASM and the American Association of Crystal Growers, Southeast Section (AACG-SE). Top posters are recognized with travel support, which allows student winners to attend professional meetings and present their research. These travel awards act as a way of disseminating the outstanding research by UT students to a larger community. In FY20, CMP assisted students financially in presenting their research at the Materials Science & Technology Technical Meeting and Exhibition (MS&T19) and the TMS Annual Meeting and Exhibition in San Diego.

Participants at the CMP Winter Synthesis Workshop at JIAM in December 2019.

At MS&T19, undergraduates Caitlin Harpel, Madeline Loveday, Samantha Maness, Sabrina McCoy, Natalie Wieber, Quinton Wright, and Morgan Yount presented their research, attended technical sessions, and represented the UT Materials Advantage chapter. Reece Emery, Samantha Maness, Logan White, and Sara Wonner represented UT at the TMS annual meeting.

Almost all undergraduate travel was matched through the UT OUR Travel Grant Program. Stian Romberg, now a graduate student in the Department of Mechanical, Aerospace and Biomedical Engineering (MABE) working under the direction of Assistant Professor Brett Compton and previously supported by CMP, submitted his research in the area of large-scale additive manufacturing of highly exothermic reactive polymer systems to the Society for the Advancement of Material and Process Engineering (SAMPE) and was selected for an additional publication in the SAMPE journal. The research conducted by Romberg and Compton is a great example of the collaboration between MABE and ORNL's Manufacturing Demonstration Facility (MDF).

In FY20, CMP helped partially support the purchase of a Keyance digital microscopy and tensile testing system capable of performing tests at elevated temperatures. The champions of these two research instruments are Peebles Professor Dayakar Penumadu from the Department of Civil and Environmental Engineering and UT-ORNL Governor's Chair for Nuclear Materials Steven Zinkle from the Department of Nuclear Engineering. CMP students should be able to access both of these new capabilities.

Carry over from previous years was used to purchase a new Phenom ProX desktop scanning electron microscope (SEM) and second particle size analyzer, complementary to the particle size analyzer previously purchased and supported by CMP. The latter three instruments are currently housed in the MSE Undergraduate Laboratories under the supervision of Egeland and Wetteland and are available to both CMP-supported students and industrial projects.

The UT site of the Manufacturing and Materials Joining Innovation Center (Ma2JIC), funded through the NSF Industry/University Collaborative Research Center (I/UCRC) program, continues in Phase II along with The Ohio State University (lead university) and sites at Colorado School of Mines, Lehigh University, and the international site at the University of Waterloo in Canada.

Claudia Rawn and Karen Boyce are both partially supported by the funds allocated for the administration of the UT site of Ma2JIC. Ma2JIC research interests, focused on materials joining including traditional welding and friction stir welding techniques, closely align with CMP. Industrial support of the UT Ma2JIC site comes from EPRI, Miller Electric, NASA, US Army Combat Capability Development Center (CCDC), and UT-Battelle.

Professor William Hamel and his students from MABE work closely with staff members at MDF through this program with projects on adaptive welding for power plant piping and pressure vessels and large-scale additive metals manufacturing (LSAMM) with non-gravity aligned gas metal arc welding (GMAW). In June of 2020, UT virtually hosted the summer IAB meeting, with UT President Randy Boyd delivering the keynote address.

Last December, CMP hosted a Winter Synthesis Workshop at the Joint Institute for Advanced Materials. The workshop focused on synthesizing oxide compounds using the polymeric steric entrapment (PSE) method, a technique pioneered by Professor Waltraud Kriven and her students from the University of Illinois at Urbana-Champaign. Graduate and undergraduate students from several different groups, along with faculty and CMP staff, participated in this hands-on event and synthesized various materials, including high entropy oxides and scintillator materials. Participants were enthusiastic, and several future workshop topics were discussed to keep the momentum of adding new synthesis and analysis techniques to researchers' tool belts.

On the first day of the workshop, Egeland and Sabrina McCoy held lectures on the basics of the PSE method and safety, respectively. Workshop participants then received hands-on experience by synthesizing their own sample with the technique. In the Ceramic Synthesis lab, researchers began making a variety of oxide compounds under the guidance of workshop leaders. On the second day of the workshop, participants brought samples back to their own labs to complete the final steps of the PSE method.

The PSE method is a synthesis technique for oxide materials. The technique has recently gained popularity due to its low cost and ability to produce chemically homogenous powders with small particle sizes. Since the workshop, many participants have found use for the PSE method in their own research.

In Chancellor's Professor Veerle Keppens' group, Brianna Musico and Quinton Wright have begun synthesizing high entropy oxides with the technique. They have since had success producing compositions that they were previously unable to achieve using solid state synthesis techniques. CMP workshops provide UT faculty, graduate students, and undergraduates with new tools to utilize in their research.

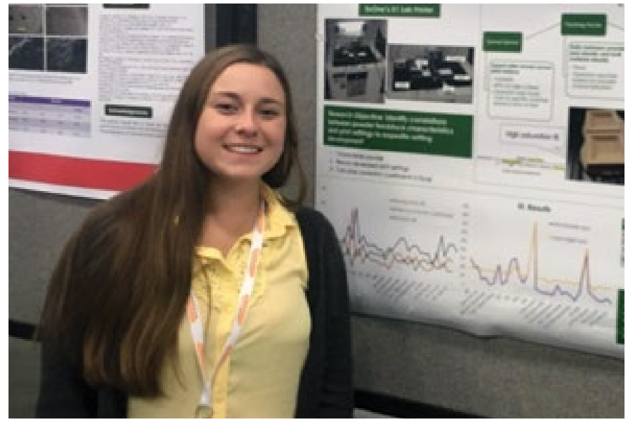
Quinton Wright presents his poster at the MS&T undergraduate poster competition in Portland/October 2019.

CMP Accomplishments

- Six facility level memberships supporting local industry
- Support packages for 14 graduate students
  - Generated 25 publications
- Funded more than 60 undergraduate students participating in research activities
  - Maness, Spurling, White awarded Goldwater Scholarships
  - Students competed in the MS&T undergraduate poster competition and participated at the TMS annual meeting
  - Success at EUReCA
    - Eikel: First (Engineering Division) and Gold (Office of Undergraduate Research award)
    - Heldt/White: Third (Engineering Division)
- Hosted Winter Synthesis Workshop
- Co-sponsored and co-hosted student night with 38 poster entries
- Replaced aging workhorse benchtop scanning electron microscope
- Virtually hosted the Manufacturing and Materials Joining Innovation Center (Ma2JIC) Industrial Advisory Board summer meeting and submitted joint proposal to the National Science Foundation for moving to Phase III.

Future Goals and Plans

The overarching goal for CMP in FY21 is to support our materials processing constituencies by increasing our industrial memberships while leveraging our graduate support packages, scholarships, and undergraduate research assistants. CMP has identified new laboratory spaces in UT's Science and Engineering Research Facility housing a set of instruments for CMP-supported activities. Our future plans include continuing to increase the number of graduate support packages, providing professional development activities for our undergraduate students, and strengthening the center's involvement with industry partners. These plans will be supported by identifying, purchasing, maintaining, and supporting equipment related to materials processing for CMP-supported students and industrial members.



Natalie Wieber presents her poster one of the MS&T posters session in Portland/October 2019.

Schedule 7

CENTERS OF EXCELLENCE ACTUAL, PROPOSED, AND REQUESTED BUDGET

Institution: THE UNIVERSITY OF TENNESSEE, KNOXVILLE Center: MATERIALS PROCESSING

	FY 2019-20 Actual			FY 2020-21 Proposed			FY 2021-22 Requested		
	Matching	Appropr.	Total	Matching	Appropr.	Total	Matching	Appropr.	Total
Expenditures									
Salaries									
Faculty	$ 182,509	$ 108,434	**$ 290,943**	$ 200,760	$ 108,434	**$ 309,194**	$ 220,836	$ 110,603	**$ 331,439**
Other Professional	60,990	59,065	**120,055**	656,096	45,000	**701,096**	721,705	35,900	**757,605**
Clerical/ Supporting	111,218	50,033	**161,251**	122,340	50,033	**172,373**	134,574	51,034	**185,607**
Assistantships	241,733	164,885	**406,618**	265,906	200,000	**465,906**	292,497	250,000	**542,497**
Total Salaries	**$ 596,451**	**$ 382,417**	**$ 978,868**	**$ 1,245,102**	**$ 403,467**	**$ 1,648,569**	**$ 1,369,612**	**$ 447,536**	**$ 1,817,148**
Longevity (Excluded from Salaries)	$4,114	$2,198	**$6,312**	$ 4,525	$3,000	**$7,525**	$ 4,978	$4,000	**$8,978**
Fringe Benefits	142,347	79,662	**222,009**	156,582	81,293	**237,875**	172,240	90,307	**262,547**
Total Personnel	**$ 742,912**	**$ 464,277**	**$ 1,207,189**	**$ 1,406,209**	**$ 487,760**	**$ 1,893,969**	**$ 1,546,830**	**$ 541,843**	**$ 2,088,673**
Non-Personnel									
Travel	$ 33,600	$ 11,230	**$ 44,830**	$ 36,960	$ 5,000	**$ 41,960**	$ 40,656	$ 10,000	**$ 50,656**
Other Supplies	12,351	10,740	**23,091**	13,586	5,000	**18,586**	14,945	15,000	**29,945**
Equipment	455,573	273,646	**729,219**	501,131	120,191	**621,322**	551,244	34,347	**585,591**
Maintenance	377	2,581	**2,958**	415	3,000	**3,415**	456	4,000	**4,456**
Scholarships	163,926	20,439	**184,365**	180,319	30,000	**210,319**	198,350	35,000	**233,350**
Other (Specify):									
Media Processing	1,186	1,387	**2,573**	$ 1,305	2,000	**3,305**	$ 1,435	3,000	**4,435**
Communication	-	77	**77**	-	500	**500**	-	750	**750**
Computer Services	-	109	**109**	-	250	**250**	-	300	**300**
Grants & Subsidies	127,192	18,863	**146,055**	139,911	25,000	**164,911**	153,902	20,000	**173,902**
Contractual & Special Services	65,542	19,696	**85,238**	72,096	30,000	**102,096**	79,306	35,000	**114,306**
Other Expenditures	-	1,036	**1,036**	-	2,000	**2,000**	-	3,000	**3,000**
Total Non-Personnel	**$ 859,747**	**$ 359,804**	**$ 1,219,551**	**$ 945,722**	**$ 222,941**	**$ 1,168,663**	**$ 1,040,294**	**$ 160,397**	**$ 1,200,691**
GRAND TOTAL	**$ 1,602,659**	**$ 824,081**	**$ 2,426,740**	**$ 2,351,931**	**$ 710,701**	**$ 3,062,632**	**$ 2,587,124**	**$ 702,240**	**$ 3,289,364**
Revenue									
New State Appropriation		$ 667,504	**$ 667,504**		$ 668,800	**$ 668,800**		$ 702,240	**$ 702,240**
Carryover State Appropriation		198,479	**198,479**		41,901	**41,901**			**-**
New Matching Funds	$ 1,602,659		**1,602,659**	$ 2,351,931		**2,351,931**	$ 2,587,124		**2,587,124**
Carryover from Previous Matching Funds			**-**			**-**			**-**
Total Revenue	**$ 1,602,659**	**$ 865,983**	**$ 2,468,642**	**$ 2,351,931**	**$ 710,701**	**$ 3,062,632**	**$ 2,587,124**	**$ 702,240**	**$ 3,289,364**

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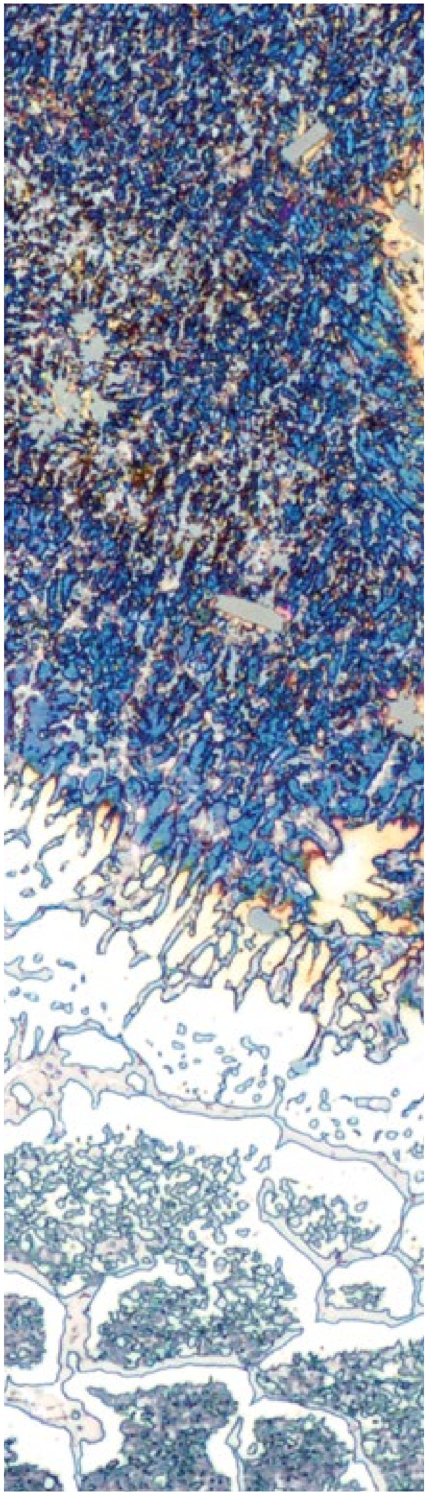

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