# Contents

## A Closer Look

1. About IMR
2. FY2018 Impact
3. IMR Strategy

## Programs and Centers

4. Materials & Manufacturing for Sustainability
6. Innovation Lab
8. Manufacturing Initiatives
12. Center for Emergent Materials
16. OSU Materials Research Seed Grant Program

## Core Materials Facilities

20. Nanotech West Laboratory
22. Center for Electron Microscopy and Analysis
24. NanoSystems Laboratory
26. Semiconductor Epitaxy and Analysis Laboratory

## Community

28. OSU Materials Week
31. Distinguished Lecture Series
32. Conferences
34. Additional Highlights

## More Info

36. FY2018 Financial Overview and Impact
38. Members
40. Staff
ABOUT IMR

The Ohio State University’s Institute for Materials Research (IMR) is a campus-wide, multidisciplinary institute that promotes and coordinates research activities and infrastructure related to the science and engineering of materials throughout The Ohio State University. Established in 2006, IMR is a unit of the University’s Office of Research, and is also supported by the College of Engineering, College of Arts and Sciences, Fisher College of Business and the Office of the Provost. More than 250 Ohio State faculty members from 35 academic departments and 10 colleges are IMR members. The institute manages extensive internal programs to support its faculty and students through seed grant funding, conference and workshop development, proposal development for major block proposals, and outreach efforts including industrial and international cooperative agreements. IMR also operates and/or supports a broad collection of shared core research facilities which allow Ohio State’s materials community to carry out state-of-the-art research while providing world-class educational experiences to students through the use of these facilities. The Materials and Manufacturing for Sustainability (M&MS) program is a university-wide initiative coordinated by IMR supporting Ohio State’s goal to become pre- eminent in the field of advanced materials and technologies for sustainability. M&MS is building on Ohio State’s existing interdisciplinary strengths in materials, world-class facilities and nationally-recognized centers of excellence, and exploiting industrial consortia and existing strategic investments to enable a convergence in the materials community’s approach to research that brings together experts from various disciplines and, ultimately, allows the full articulation of research and innovation processes.
<table>
<thead>
<tr>
<th>Category</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faculty Members</td>
<td>250+</td>
</tr>
<tr>
<td>Departments</td>
<td>35</td>
</tr>
<tr>
<td>Colleges</td>
<td>10</td>
</tr>
<tr>
<td>Publications Per Member</td>
<td>9</td>
</tr>
<tr>
<td>Citations Per Member</td>
<td>475</td>
</tr>
<tr>
<td>Patents Filed</td>
<td>119</td>
</tr>
<tr>
<td>Patents Issued</td>
<td>31</td>
</tr>
<tr>
<td>Invention Disclosures</td>
<td>104</td>
</tr>
</tbody>
</table>

1 Average of researchers found on Google Scholar in CY2017
2 Office of Economic and Corporate Engagement
The Institute for Materials Research’s strategic plan is driven by the goal to support and grow research excellence and impact by our students, staff and faculty to position Ohio State as a world-leader in materials research and innovation.

VISION

The Ohio State University Institute for Materials Research provides vision, coordination and support to advance multi-college excellence and impact in interdisciplinary, materials-allied research and innovation. We are further building on this foundation to evolve the university’s culture and land-grant mission to include a convergent approach to solving the most pressing grand challenges of the 21st century through the translation of research, knowledge and assets.

MISSION

- Nurture, grow and support excellence in materials-allied research at Ohio State;
- Assist the advancement of research team development;
- Provide strategic planning, resources and infrastructure, as well as educational and outreach activities;
- Connect, create and deliver value for our students, staff, faculty and industry collaborators;
- Enable long-term, mutually beneficial innovation partnerships between industry partners and Ohio State students, faculty and staff.

To realize success for the IMR vision, we have developed six IMR goals, as shown below. These goals are rolling over a four-year cycle with diagnostic assessments every six months to maintain relevancy.

1. Create a sustaining innovation ecosystem
2. Grow and sustain research pre-eminence
3. Enable internal culture of transdisciplinary research and innovation
4. Establish an experiential learning environment for innovation
5. Build and expand dynamic linkages with the private and public sectors, from local to global
6. Ensure sustainable, state-of-the-art infrastructure, operational effectiveness and efficiency
The Materials and Manufacturing for Sustainability (M&MS) focus area of The Ohio State University’s Discovery Themes enables Ohio State faculty, students and staff to focus on translational research and innovation in technology, science and manufacturing as they apply to future energy systems and sustainability from the nano to the macro scale.

With the goal to become pre-eminent in the field of advanced materials and technologies for sustainability, our program connects and creates value while delivering impact to solve the world’s most pressing problems in the 21st century.

M&MS builds on the foundation of discovery in the Institute for Materials Research, hiring faculty to advance materials discoveries, developing strategic industrial and global relationships, and accelerating the research process to enable a paradigm of discovery-to-deployment at Ohio State.

During the past year, M&MS has become a well-advanced program. We hired our third cohort of M&MS faculty and innovation leaders; the Innovation Laboratory is now a fully functioning arm of the institute; we are enabling interdisciplinary collaborations on a local to global scale; and we are establishing new core material facilities. All of this is ramping while our existing centers continue to push the leading edges of their fields and our seed programs are building the teams and centers of the future.

INVESTMENTS OCCUR IN THREE CLUSTER AREAS, SPANNING FROM SCIENCE TO MANUFACTURING

• Energy harvesting, storage and systems
• High-performance materials and structures
• Materials for sustainable information processing
Our faculty members are central to the strength and success of IMR’s expanding materials community. In the past three years, the M&MS cohort at Ohio State has grown to include 23 faculty members. Those new hires span a myriad of departments and multiple colleges, reflecting the campus-wide scope of the M&MS Discovery Theme program, which advances and accelerates materials research and innovation spanning from science to manufacturing, as they apply to future energy systems and sustainability. During the 2017-18 academic year, five faculty members joined Ohio State through the M&MS program.

Photos from top to bottom:

SHAMSUL ARAFIN Assistant Professor, Department of Electrical and Computer Engineering

ASHLEY BIGHAM Assistant Professor, Austin E. Knowlton School of Architecture

MICHAEL GROEBER Associate Professor, Department of Integrated Systems Engineering

ZACHARY SCHULTZ Associate Professor, Department of Chemistry and Biochemistry

RUIKE ZHAO Assistant Professor, Department of Mechanical and Aerospace Engineering

Joanna joined IMR in January, bringing her six years of professional experience at Ohio State to the institute. Her goal is to enhance existing, internal funding programs and find optimal external funding opportunities for IMR awardees and new faculty teams.

Mike leverages his experience as a reporter and editor in his new position, telling stories that illustrate the important roles materials play in our daily lives. It is his job to communicate the advancement, impact and innovation of materials research at Ohio State.

Ryan oversees communications for IMR and the Department of Electrical and Computer Engineering. He is a seasoned storyteller who utilizes his more than 16 years of journalistic experience to shine a light on research achievements and engineering education.
THE INNOVATION LAB

The Innovation Lab is an open-area, shared space that encourages conversation, collaboration and creativity. The lab’s vision is to make innovation as strong as research. It is a place where partners have access to the university and engage with both students and faculty. The Innovation Lab is a space focused on convergence and translation of IMR’s knowledge and assets to solve real-world problems. It is the interface that connects, creates and delivers impactful value derived from interdisciplinary research to meet the needs in the market through collaboration and strategic partnerships.

This is leading to an interdisciplinary, innovation culture that, in a little over a year since being built, has connected more than 20 faculty and 280 undergraduates, from 42 departments and 6 colleges, spanning from History to Engineering, and everything in between, to companies that range from start-ups to Fortune 500s. This has led to the creation of more than 100 externships and over 10 internships. We also have attracted state funding to engage community college students to attract a wider array of talent and skills for collaborations with regional, industry partners. Thanks to the Innovation Lab, we now have more than 30 companies engaged in multiple ways that will enable long-term, mutually-beneficial relationships with students, faculty and external partners.
TEACHING AND LEARNING

The Innovation Lab is where students wanting real-world, experiential learning are connected with companies wanting better access to the university and undergraduates through externship opportunities. Externships, in this context, are a unique type of internship defined as on-campus partnerships between students, the university, and potential employers that formally integrate students’ academic study with work during either a weekend or weeklong INNOVATE-O-thon. These INNOVATE-O-thon’s are the result of a strong collaboration with the Center for Innovation and Entrepreneurship, industry partners, and the broader Ohio State community that allow students to participate in a unique, community-engaged learning environment where the focus is on talent, skills, and inclusiveness.

INNOVATE-O-THON
SEVERAL TIMES A YEAR, IMR INVITES A SELECTED COMPANY’S REPRESENTATIVES TO CHALLENGE UNDERGRADUATES TO DISSECT A REAL PROBLEM AND DEVISE AND PROPOSE A SUITABLE, EXECUTABLE SOLUTION TO THAT COMPANY. During the events, students form interdisciplinary teams to create innovative solutions to support the needs of that company. From brainstorming to project budgeting, students are given the reins to produce the best concept.

In FY2018, The Ohio State University’s energy partner ENGIE challenged students to help achieve one goal: improve energy efficiency through positive behavioral changes on campus. Faculty members hired through different focus areas of the Ohio State’s Discovery Themes Initiative joined nearly 50 students from across colleges to try their hands in helping shape the future of energy consumption at the land-grant university. IMR collaborated with Ohio State’s Center for Innovation and Entrepreneurship for this and the following event.

Later that year, IMR and Wexner Medical Center teamed up for the first time for an experimental INNOVATE-O-thon with Honda R&D Americas, Inc. that challenged students to find novel approaches to improving mobility. The five-day externship program, hosted by IMR, Wexner and the Center for Design and Manufacturing Excellence, pushed students from brainstorming a concept to building a prototype. As they did for the ENGIE event, undergraduates, faculty and industry came together at IMR's Innovation Lab. For the first time, IMR collaborated with the Ohio Manufacturing Institute to include students from a technical college, Marion Technical College, who joined the event with support from the Ohio Department of Higher Education’s Ohio Means Interns and Co-ops Program.

CHUCK TYLER joined the Institute for Materials Research in August 2017 as Graduate Administrative Associate. In this position, he provides marketing, finance and strategy support for the institute.

Tyler spends most of his time at the Innovation Lab, where his 12 years of business administration experience are applied in the execution of a diversity of duties that advance IMR’s day-to-day operations and long-term goals. His work aids the success of professional researchers and students alike, as they make discoveries in our labs.
Ohio State plays a crucial role as a testbed for today’s and tomorrow’s advanced manufacturing. Offering translational applied research, education, and technologies that will transform the advanced manufacturing landscape, Ohio State leads the future of manufacturing through an IMR-led, overarching strategy for Ohio State’s manufacturing initiatives that include our partners, the Ohio Manufacturing Institute and the Center for Design and Manufacturing Excellence.

OHIO MANUFACTURING INSTITUTE

The mission of the Ohio Manufacturing Institute (OMI) is to serve as an action-oriented public policy arm for manufacturing within the state and nation, reflecting a thoughtful and sustained response to industry-led and vetted issues. We also serve as a state-wide facilitator that supports manufacturers, especially small to medium-size firms within the supply chain, by aligning industries, academic institutions, technology support organizations and government toward common technical and workforce solutions.

HOW DOES OMI SERVE MANUFACTURING?

- Develop industry-vetted, well-researched policy recommendations and best practices that support manufacturers, especially small- and medium-sized manufacturers
- Remove barriers and help to make university innovation resources more accessible to industry
- Offer insights into product innovation and commercialization practices, from large and small manufacturers to entrepreneurs
- Support access to best-practice workforce development resources, e.g., project-based student internships and predict future skills that will be required
- Promote manufacturers’ innovation stories to policy makers and the public through Manufacturing Tomorrow podcast series
FY2018 PROJECTS INVESTIGATING SOLUTIONS TO MANUFACTURERS’ MOST VEXING CONCERNS:

- Research on “Retooling Engineering Technology for the Manufacturing 5.0 Workplace” analyzed occupational skill requirements, employment projections and observations from employers to provide a better understanding of education and training needs that serve the region.
  - Presented findings to the Federal Reserve Bank of Atlanta and Upjohn Institute, Ohio TechNet college participants and regional manufacturers
  - As a result of the research, OMI is collaborating with leadership, faculty and industry partners at Ohio State to develop a bachelor’s degree in engineering technology to be offered at regional campuses.

- Led statewide industry engagement team supporting the Ohio Innovation Exchange, a web portal that enables business, industry and academic visitors to more easily find, connect, and collaborate with each other. The single, searchable and open website provides access faculty experts, state-of-the-art university equipment, and research support services.

- Completed work on a $2.24M Department of Defense Office of Economic Adjustment Defense Manufacturing Assistance Program. As with the first phase, DMAP Grant 2 offered market diversification, operations management and marketing assistance to the Ohio defense supply chain. In addition, we engaged the communities of Akron, Beavercreek, Coshocton and Licking County in strategic economic development assistance. Impacts include:
  - 36 companies and six community projects engaged, with 81 company projects completed
  - During DMAP 2, 27 companies reported $45M in new sales, 167 new jobs filled, 620 new customers and 80 new products and added capabilities.

- Engaged in the Lightweight Innovations for Tomorrow Accelerator Team and the Ohio Manufacturers’ Association Workgroup on Manufacturing Careers to align industry needs to regional education and training resources informed by national best practices.

- As PI, coordinated the Ohio Means Internships & Co-ops program, a unique internship program funded by the Ohio Department of Higher Education in which community college and university students work at firms on advanced manufacturing projects.
  - OMIC 4 teamed up with IMR’s Innovate-O-thons to encourage community college participation in these weekend and weeklong product development and prototyping externships. Five Marion Tech students were involved in the May 2018 session on healthcare mobility solutions.
The mission of the Center for Design and Manufacturing Excellence (CDME) is to utilize the technical assets and expertise of The Ohio State University’s world-class faculty, staff, students, and centers to be the foremost leader in commercialization through applied research by using business validation, process innovation, integrated design, and best of class manufacturing approaches.

CDME was developed to meet the translational research needs of the university’s external partners. The center was funded initially via a $6.8M federal grant from the Department of Defense and by the College of Engineering to ensure that university innovation provides a more direct impact on the commercial manufacturing industry. In addition to its operation as an applied engineering research center, CDME is the home of the Ohio Manufacturing Extension Program (MEP) for Central and Southeastern Ohio (37 counties), the Experiential Entrepreneurship Education (E3) Program, and I-Corps@Ohio - the only statewide innovation training program sanctioned by the National Science Foundation.
HOW DOES THE CDME HELP INDUSTRY?

• Innovate for differentiation
• Improve productivity
• Increase quality
• Lower costs
• Improve sustainability
• Frequently host manufacturing-centric events
• De-risk industry’s participation and investment in new technology
• Build future workforce of industry-ready students in design, manufacturing, engineering, and technology innovation

FY2018 HIGHLIGHTS OF PROJECTS HELPING INDUSTRY UTILIZE THE TECHNICAL ASSETS OF OHIO STATE AND APPLIED RESEARCH SERVICES OF OUR TEAM:

• Industry projects for FY 2018 (July 1, 2017-June 30, 2018) quantified:
  » Number of projects: 118
  » Number of small company projects: 56
  » Number of large company (>800 employees) projects: 35
  » Faculty/Department projects: 18
  » Government projects: 9
  » Total revenue from projects: $6,860,974 (Average $58,143)

ADDITIONAL FY2018 HIGHLIGHTS

• CDME moved into a national leadership position for Additive Manufacturing. The center brought on board new team members: Dr. Ed Herderick (from GE’s additive program) to lead the initiative, Jacob Rindler (previously with Northrup Grumman’s additive manufacturing innovation team), and Dr. Xu Zhang for his experience with biomedical project commercialization. Ed’s team is complemented by one of most diverse additive manufacturing labs in a university environment, comprised of virtually every additive modality. The marque equipment in the additive laboratory consists of a Conceptaser M2 (dual beam laser powder bed), an Arcam Q10+ electron beam powder bed, an ExOne Innovent and a custom designed GMAW DED system. The ConceptLaser and Arcam systems were provided as part of a partnership between CDME and Proto Precision Additive. The ExOne was procured as part of a collaboration with ExOne for joint alloy and powder development programs. These systems and the dozen plus polymer/ceramic 3D printers are already being deployed for advanced component design, alloy/powder characterization and standards development for the military, automotive industry, biomedical companies and university researchers.

• Became member of Ohio Manufacturers’ Association
• Became member of America Makes
• Renovations complete for new electrical engineering laboratory
• Norm Chagnon hired as Program Director for I-Corps@Ohio
• I-Corps@Ohio awarded $1M through state FY2019
• CDME hosts its first annual Manufacturing Day celebration. We had 70 people attend from industry, the university and area high schools.
• Partnered with two companies who host on-demand manufacturing training with a library of over 1,200 tutorials
• Hires: Dr. Ed Herderick, Director of Additive Manufacturing; Marc Purslow, Director of Advanced Materials Processing; Jacob Rindler, Lead Additive Engineer; Dr. Xu Zhang, Lead Biomedical Additive Engineer
• Hosted 24 events throughout Ohio
• Experiential Entrepreneurship Education (E3) program was launched
The Center for Emergent Materials (CEM) is Ohio State’s National Science Foundation-funded Materials Research Science and Engineering Center. It seeks to discover and engineer emergent materials through innovative transdisciplinary science that enable novel phenomena and phases. CEM research focuses on the understanding and control of magnetism in novel materials and materials systems, and on exploration of emergent electronic and magnetic phenomena. Interdisciplinary teams of faculty, students and postdoctoral researchers are addressing the multi-faceted scientific issues this challenge presents by integrating materials synthesis/growth, characterization, novel probe development, and theory and modeling. CEM seeks to enhance the strong scientific community essential to the future of this endeavor through vigorous engagement in improving participation by the relatively untapped resources of women and underrepresented minorities. CEM’s programs integrate the excitement and potential of the Center’s research into public outreach and education programs that dovetail with recruitment and teaching of diverse communities at all levels — from K-12 students extending through undergraduates, graduates, and postdocs.

**SCIENTIFIC & TECHNOLOGICAL IMPACTS**

CEM seeks to establish foundations for three areas of materials research important to the nation’s scientific vitality and the technological prowess that strengthens the economy and improves quality of life. IRG-1 focuses on advancing fundamental understanding of magnetism in multi-orbital systems as a foundation for designing new magnetic materials and searching for novel states of matter. IRG-2 seeks to realize robust two-dimensional topological phases including quantum spin Hall and quantum anomalous Hall insulators with dissipationless edge currents and to create new opportunities for understanding spin behavior in reduced dimensions. IRG-3 seeks to explore a new regime of spin transport by studying spin fluxes in magnetically textured materials that, if successful, could enable new paradigms for spin transport and new approaches to manipulation and control in spintronic devices.

**IRG-1: SPIN-ORBIT COUPLING IN CORRELATED MATERIALS: NOVEL PHASES AND PHENOMENA**

By combining of established efforts in new materials discovery, a diverse suite of characterization tools, and varied approaches to theoretical modeling, IRG-1 researchers seek to establish foundations for the rich, unfolding arena of magnetism of oxides containing 4d and 5d transition metal ions, and to discover topological properties in quantum materials. Two key features, strong spin-orbit coupling (SOC) and a relatively large radial extension from the nucleus, underlie the surprising new magnetism arising from 4d and 5d oxides. The presence of strong spin orbit coupling significantly alters the interplay of spin, orbital, charge, and lattice degrees of freedom, while the larger size of the 4d/5d orbitals impacts superexchange interactions and the tendency toward orbital ordering. These phenomena offer a richness that enables both the design of new magnetic materials and the search for novel states of matter. Topological states of matter, such as Dirac and Weyl semimetals, leave their imprint in spectroscopy and in thermomagnetic transport; both aspects have been explored theoretically and experimentally. The combination of SOC and Dzyaloshinskii-Moriya interactions (DMI), in crystals with broken bulk inversion symmetry and/or magnetic multilayers with broken surface inversion symmetry, gives rise to a variety of interesting spin textures, including skyrmions.

Understanding the ferromagnetic insulating state in double perovskites with 5d ions: Among the vast family of magnetic oxides, true ferromagnetic insulators are rare. A select few A$_2$BB’O$_6$ double perovskites (DPs), such as Ba$_2$ZnReO$_6$ and Ba$_2$NaOsO$_6$, belong to this exclusive group. Why these DPs are ferromagnetic, while seemingly similar DPs are not,
is a puzzle whose answers have eluded researchers for many years. Other mysteries surrounding these unusual ferromagnets include a negative Weiss temperature, missing entropy at the phase transition, and temperature dependent effective moments. Theoretical work by IRG-1 researchers has provided an explanation for this enigmatic behavior. The onset of anisotropic orbital ordering at a temperature well above TC stabilizes the ferromagnetic state and explains the other unusual aspects of magnetism in these compounds. This novel pattern of orbital ordering is extremely sensitive to lattice distortions, which means that seemingly subtle distortions of the structure stabilize competing patterns of orbital order that destabilize the ferromagnetic ground state.

Effects of lattice distortions and defects on magnetism: IRG-1 researchers have demonstrated that subtle lattice distortions and defects in 5d oxides can have surprisingly large effects on magnetism. In A$_2$BB’O$_6$ perovskites lattice distortions driven by changes in the surrounding diamagnetic cations (i.e. chemical pressure) can be used to control the degree of SOC and alter the pattern of orbital ordering, both of which can have large effects on the magnetism. One such example is cubic Ba$_2$LuReO$_6$ whose Neél temperature is more than three times smaller than the isoelectronic, tetragonal Sr$_2$MgOsO$_6$. Careful electron microscopy studies show that the puzzling observation of magnetism in Ba$_2$YIrO$_6$ (Ir$^{5+}$ [5d$^4$]) with nominally J=0 local atomic moment is not intrinsic but originates from Y/Ir antisite defects.

**IRG-2: CONTROL OF 2D ELECTRONIC STRUCTURE BY SURFACE CHEMISTRY AND PROXIMITY EFFECTS**

IRG-2’s overall goal is to understand the influence of surface chemistry and magnetic proximity effects in two-dimensional (2D) materials on their spin-orbit coupling, electronic band structure, and magnetic ordering (exchange splitting), in order to realize robust two 2D topological phases including quantum spin Hall (QSH) and quantum anomalous Hall (QAH) insulators. To this end, IRG-2 employs an integrated theory-synthesis-measurement approach to create and explore a variety of 2D and quasi-2D systems that have high spin-orbit coupling and ferromagnetic (FM) ordering. IRG-2’s synergies between theoretical modeling, bulk and thin film synthesis, material characterization, device fabrication and electron transport, scanning tunneling microscopy (STM), optical spectroscopy, angle-resolved photo-emission spectroscopy (ARPES), and sharing of samples under air-free conditions are essential for this program.

Developing the 2D group-IV graphane analogues germanane and stanene, where ligand termination can tune the band gap, topological character, and interactions with the surrounding environment. Going from Ge to Sn reduces the band gap and increases spin-orbit coupling, potentially enabling band inversion and the QSH phase.

Controlling magnetic proximity effects between 2D materials and underlying magnetic materials via magnetic material design, interface structure, and strain. We are evaluating how magnetic exchange can be induced with different FM materials including those where the easy axis can be tuned (CoFe$_2$O$_4$) with different interfacial orbital overlap, V(TCNE)$_2$ with its varying degrees of order, and super-paramagnetic iron oxide nanoparticles (SPIONS). Stacking 2D materials onto these substrates will enable 2D topological phases by combining high spin-orbit coupling, exchange splitting, and high mobility transport through encapsulation and proximity effects.
IRG-3: SPIN FLUX THROUGH ENGINEERED MAGNETIC TEXTURES: THERMAL, RESONANT AND COHERENT PHENOMENA

IRG-3 seeks to understand fundamental aspects of spin dynamics and spin flux in textured magnetic environments. Spin chemical potential gradients generated by diverse means are used to drive, confine and manipulate spin/magnon excitations and explore interactions enabling spin transport in new regimes through an integrated experimental and theoretical program that employs novel materials and structures. The materials under investigation include low damping magnetic insulators and metals as well as high mobility semiconductor materials. IRG-3 Major Accomplishments:

- Discovery of two length scales for magnon transport in magnetic insulator films: IRG-3 researchers investigated two distinct magnon relaxation mechanisms for the magnon spin relaxation and magnon energy relaxation through a collaborative effort using the spin-Seebeck effect in a series of Pt/YIG/GGG heterostructures with various Y$_3$Fe$_5$O$_{12}$ (YIG) film thicknesses. The spin Seebeck signals exhibit a non-monotonic YIG thickness dependence, revealing two relaxation length scales of ~10 mm (for magnon spin relaxation) and ~250 nm (for magnon energy relaxation), which was explained by IRG-3 theoretical modeling of the magnon spin chemical potential and magnon-phonon relaxation at interfaces.

- Optical readout of dynamic spin transfer from paramagnetic P1 spins in diamond by nitrogen-vacancy (NV) centers: Optically detected magnetic resonance of NV centers provides an excellent platform for high sensitivity nanoscale magnetic resonance spectroscopy. IRG-3 researchers discovered that NV spins are selectively sensitive to spin dynamics of resonantly excited P1 centers in diamond enabling NV-based non-resonant broadband detection. This unexpected, non-resonant, phonon-mediated transfer of spin polarization between P1 defects and NV-center in diamond provides a new method for performing high sensitivity paramagnetic resonance spectroscopy using NV centers over a broad field-frequency range.

- Engineering the spectrum of dipole field-localized spin wave modes to enhance spin-orbit torque anti-damping and auto-oscillations: Auto-oscillation of a ferromagnet due to spin-orbit torques is of wide interest for generating high frequency magnetic dynamics. IRG-3 researchers demonstrated that field localization generates a series of well-resolved localized modes in the presence of spin currents arising from the spin Hall effect in Py/Pt via spin-torque FMR measurements. This tunability of the localized modes potentially provides a platform for understanding the multi-mode interaction mechanism in spin-Hall oscillators, and for optimizing spin-Hall oscillators as spintronics devices.

EDUCATION, OUTREACH & DIVERSITY (EHRD)

The CEM strives to increase the quantity and quality of scientists and engineers well-prepared to contribute to and lead research, development, and commercialization in materials-related fields and to help enable enhanced career opportunities for diverse communities of students and potential scientists. Through focused, coordinated and sustained activities that engage the broad CEM membership in outreach extending from elementary school students through faculty ranks, the CEM addresses three specific objectives: (1) enhancing classroom education; (2) creating research internship opportunities and professional development across educational levels; and (3) widening the Science-Technology-Engineering-Math (STEM) pathway, particularly in materials-related disciplines. Tightly interwoven with the EHRD activities are the Diversity Enhancement activities, which are aimed at enhancing diversity in science and engineering by eliminating barriers to the success of underrepresented groups.
EHRD MAJOR ACCOMPLISHMENTS

During this reporting period, the CEM engaged in education, training, and outreach programs that impacted over 1,600 K-12 students, 32 K-12 teachers, over 3,500 undergraduates in classes, 25 undergraduate researchers including REU students, 48 graduate students and 10 postdoctoral researchers.

CEM continues to develop and implement a set of guided group work sessions for graduate quantum mechanics, electro-dynamics, and classical mechanics. These have especially benefitted Bridge Program (OSU-BP) students. For undergraduates, this includes online “essential skills” mastery tasks for the large introductory physics sequences (over 4000 students/year) and measured large gains in skills. At the high school level, CEM partners in a program to improve materials science-focused high school courses for 20 teachers across 14 school districts in Ohio. At the K-8 level, their Scientific Thinkers program launched a new effort to engage families in math and science through an evening event at the high-poverty-status school where undergraduate and graduate student volunteers led science and math activities for the families.

CEM and NMHU are continuing with an active PREM program, including multiple visits and research seminars from OSU faculty, hosting 2 REU students in summers 2016-2018, and hosting an NMHU graduate student and NMHU postdoc. The CEM also continues to deliver key support for the M.S.-Ph.D. Bridge Program, which has completed its fourth year, and confirmed internal funding to continue the program. The OSU-BP continues to have dramatic impact on the diversity of the graduate program.

SEED PROGRAM

A vigorous seed program that supports new ideas and incubation of multidisciplinary teams augments CEM interdisciplinary research endeavors. The seed program operates in partnership with two internally funded Centers: the Institute for Materials Research (IMR) and the Center for the Exploration of Novel Complex Materials (ENCOMM). This partnership broadens the impact of all three centers in the OSU materials community and better leverages resources. Components of current IRGs originated from the CEM seed program. The program strongly encourages proposals from junior and underrepresented faculty.

SHARED RESEARCH FACILITIES

CEM plays a vital role in materials research facilities at OSU most notably with the NanoSystems Laboratory (NSL) to whom it provides staff support. CEM members have historically been instrumental in the acquisition of equipment through either federal or internal OSU grants. CEM maintains funding for emergency repairs and installation such as for the installation of an inductively coupled plasma reactive ion etching system. CEM teams with others in applying university equipment investment in equipment that is installed in NSL. The addition of these tools directly benefits CEM research, as well as the OSU materials and central Ohio community at large. The Chair of the User’s Committee is a CEM investigator (Lau).

COLLABORATIONS AND INDUSTRIAL INTERACTIONS

Established collaborations with industrial partners and national laboratories enhance CEM scientific endeavors and improve CEM productivity. CEM’s industry relationships support graduate students, provide resources to move technologies from the lab to market and provide students access to this career path. A particularly fruitful center-to-center collaboration continued with the Leibniz Institute for Solid State Research (IFW) in Dresden, Germany. Air Force Research Labs is a promising new collaboration this period. CEM collaborations led to 18 papers with national labs and 1 paper with an industry collaborator.
The OSU Materials Research Seed Grant Program provides multiple tiers of internal funding opportunities to support basic, nascent research, stimulate and grow research teams into focused research groups and centers, translational R&D with industry partners, global partnership opportunities, and IMR also provides critical support for faculty to access core user facilities within IMR's network of shared laboratories. The Exploratory Materials Research Grants ($40k per award), Multidisciplinary Team Building Grants ($60k per award) and Proto-Interdisciplinary Research Groups ($80k per award are coordinated by IMR and are co-funded with resources from IMR, Center for Emergent Materials and ENCOMM (Center for Exploration of Novel Complex Materials). These three tiers provided $560,000 in funding to 15 Ohio State researchers from six departments in three colleges in FY18. Additionally, IMR awarded 18 Kickstart Facility Grants totaling $45,000 to Ohio State researchers across nine departments in four colleges for critical access to shared experimental facilities and provided $20k to a team via an IMR Industry Challenge Grant that was matched with $20k from the industry partner. IMR is also continuing its Global Partnership Grant program through a targeted effort with the Indian Institute of Technology – Bombay (IIT-B) with support to two research teams paired with IIT-Bombay faculty and students.
**FY18 EXPLORATORY MATERIALS RESEARCH GRANTS**

Exploratory Materials Research Grants enable nascent and innovative materials research to advance to the point of being competitive for external funding. Three Exploratory Materials Research Grants were awarded this year:

- **Mechanoelectric effects on bone mineralization as a stiffness modulator** — Principal Investigator: Hanna Cho, Department of Mechanical and Aerospace Engineering; Co-investigators: Soheil Soghrati, Department of Mechanical and Aerospace Engineering; Do-Gyoon Kim, Orthodontics

- **Investigation of Boron-Based III-V Compound Semiconductors** — Principal Investigator: Tyler Grassman, Department of Materials Science and Engineering

- **Establishing Computational and Experimental Frameworks to Elucidate Magnetoelastic Interactions in Smart Metamaterials** — Principal Investigator: Ryan Harne, Department of Mechanical and Aerospace Engineering; Co-investigator: Marcelo J. Dapino, Department of Mechanical and Aerospace Engineering

**FY18 MULTIDISCIPLINARY TEAM BUILDING GRANTS**

Multidisciplinary Team Building Grants form multidisciplinary materials research teams that can compete effectively for federal block-funding opportunities. Two Multidisciplinary Team Building Grants were awarded this year:

- **Sulfide-Based Lithium Superionic Conductors (LISICON) for All Solid-State Energy Storage Device** — Principal Investigator: Jung-Hyun Kim, Department of Mechanical and Aerospace Engineering, Materials Science and Engineering; Co-investigator: Vicky Doan-Nguyen, Materials Science and Engineering, and Mechanical and Aerospace Engineering

- **MOCVD Growth and Material Properties of Earth Abundant Semiconductor ZnSnN** — Principal Investigator: Hongping Zhao, Department of Electrical and Computer Engineering; Co-investigators: Jinwoo Hwang, Materials Science and Engineering; Aaron Arehart, Electrical and Computer Engineering

**FY18 PROTO-INTERDISCIPLINARY RESEARCH GROUP GRANTS**

Proto-IRG Grants form new interdisciplinary research groups (IRGs) that can be incorporated into the Center for Emergent Materials, an NSF Materials Research Science and Engineering Center, for renewal proposal in 2019. Four Proto-IRG Grants were awarded this year:

- **Structure, Defects and Emergent Properties at Magnetic Interfaces** — Principal Investigator: Jinwoo Hwang, Department of Materials Science and Engineering

- **Metamorphic Narrow Gap Antimonide Materials for Topological Insulators** — Principal Investigator: Sanjay Krishna, Department of Electrical and Computer Engineering

- **Tunable Ferromagnetic and Antiferromagnetic Spintronics Based on Graphene Quantum Hall States** — Principal Investigator: Jeanie Lau, Department of Physics

- **Anionic Functional Materials** — Principal Investigator: Yiying Wu, Department of Chemistry and Biochemistry
The OSU Materials Research Seed Grant Program has helped spur many vital research projects at The Ohio State University. In FY18, a multidisciplinary team of researchers at Ohio State received a $6.34 million award from the Defense Advanced Research Projects Agency (DARPA) to develop novel magnetic materials that could unlock a new paradigm for high-density, energy-efficient storage and computing.

“A new paradigm for high density, energy efficient magnetic information storage is essential to meet the rapidly intensifying need for high performance computation and information processing, key foundations for the world’s economy,” said principal investigator Mohit Randeria, a professor in the Department of Physics. “The magnetic skyrmion is a nano-scale, topologically stable spin texture that can be written, read and manipulated to meet that need.”

The six-member Ohio State team of experts in materials science and physics submitted a proposal built on a history of research on skyrmions. This competitive award grew from a series of Seed Grants made possible by ongoing collaborations funded by IMR, the Center for Emergent Materials, and the Center for Exploration of Novel Complex Materials. Co-investigator David McComb, an associate director at IMR, said it’s this combination of having one person in theory and simulation, two people growing novel materials, and three people in very advanced characterization that make this a particularly strong team.

Top: A crystalline array of skyrmion taken by transmission electron microscope at the Center for Electron Microscopy and Analysis.

Bottom: An example of magnetic spin texture in a single skyrmion.

FY18 Kickstart Facility Grants
IMR Kickstart Facility Grants strengthens near-term research proposals for external support by helping offset costs associated with research facilities and making shared campus research facilities more accessible. Eighteen Kickstart Facility Grants were awarded this year:

Quantification of the Susceptibility to Ductility Cracking in Austenitic Alloys — Principal Investigator: Boian Alexandrov, Materials Science and Engineering; Co-investigator: Samuel Luther

Tailoring Catalyst Surface Morphology for Highly Efficient Ethanol Steam Reforming — Principal Investigator: Robert Baker, Chemistry and Biochemistry

Evaluation of fungal growth in household products — Principal Investigator: Karen Dannemiller, Civil, Environmental and Geodetic Engineering, and Environmental Health Sciences; Co-investigators: Natassia Brenkus, Marcia Nishioka, Chad Rappleye and Thomas Mitchell
Insight into liquid metal embrittlement in the Fe-Zn and Fe-Cu systems — Principal Investigator: Carolin Fink, Materials Science and Engineering; Co-investigator: Dean Sage

Ultrasonic resistance spot welding of dissimilar materials — Principal Investigator: Xun Liu, Welding Engineering, and Materials Science and Engineering

Organic Redox Relay Flow Batteries for Energy-Dense, Grid-Scale Storage — Principal Investigator: Christo Sevov, Chemistry and Biochemistry

Measuring Tumor Extracellular Matrix Dynamics with Molecular Scale Force Spectroscopy — Principal Investigator: Jonathan Song, Mechanical and Aerospace Engineering; Co-investigator: Carlos Castro

Analysis of the chemical compositions of tomato fruit cuticle by using UPLC-MS and GC_MS for plant health and quality — Principal Investigator: Ye Xia, Plant Pathology

Fast Charging Thiazyl Radical Battery — Principal Investigator: Shiyu Zhang, Chemistry and Biochemistry

Structural Characterization of Silver-DNA Supramolecular Assemblies and Nanoparticles — Principal Investigator: Yuyuan (Tom) Zhang, Chemistry and Biochemistry

In-situ TEM heating experiment to study effects of cyclic thermal gradients in metal powders under AM growth conditions — Principal Investigator: Joerg R. Jinschek, Materials Science and Engineering

Effect of fixatives on oxidation state of iron — Principal Investigator: Gunjan Agarwal, Biomedical Engineering

Controlling Silanol Dimer Proximity to Alter Catalytic Activity — Principal Investigator: Nicholas Brunelli, Chemical and Biomolecular Engineering

Evaluating Micropatterning to Control Ocular Cell Behavior — Principal Investigator: Heather Chandler, College of Optometry

Rapid Synthesis and Identification of Local Structure Evolution in Sulfide-based Solid Electrolytes — Principal Investigator: Vicky Doan-Nguyen, Materials Science and Engineering, Mechanical and Aerospace Engineering

Atomic layer deposition of lattice-matched alumina and vanadium dioxide films — Principal Investigator: Nima Ghalichechian, Electrical and Computer Engineering

Development of All Solid-State High-Voltage Lithium-Ion Batteries — Principal Investigator: Jung-Hyun Kim, Mechanical and Aerospace Engineering, Materials Science and Engineering

Fabrication of high performance nuclear energy harvest device using SiC and AlN — Principal Investigator: Lei Raymond Cao, Mechanical and Aerospace Engineering

FY18 IMR INDUSTRY CHALLENGE GRANT
Industry Challenge Grants strengthen new collaborations between Ohio State researchers and private industry partners in materials-allied research.

Fundamental hydrocarbons science at the single molecule level — Principal Investigator: Jay Gupta, Associate Professor, Department of Physics
Nanotech West Laboratory (NTW) is the largest, most comprehensive micro- and nanofabrication user facility in Ohio. It is a shared-user facility, open to both academia and industry, with more than 24,000 square feet of laboratory, administrative and support space. NTW houses an extensively equipped and fully staffed 6,000 square-foot cleanroom with multiple, full device process flows, major shared facilities for semiconductor and oxide epitaxy, materials and device characterization, and shared labs for research on energy storage materials and biomaterials and devices.

Driven by IMR’s Materials and Manufacturing for Sustainability Discovery Theme, and new faculty recruitment, NTW has recently seen the installation of equipment and the enhancement of various lab spaces to support new capabilities and additional research thrusts. New lab spaces that are now open or currently under development include: the Innovation Lab (dedicated to collaborative industry interactions and outreach), the Mid-Infrared Characterization and Application Lab (enabling infrared pixel and full array characterization), the Energy Storage Hub (dedicated to battery related materials synthesis research) and the expansion of the metal organic chemical vapor deposition lab to include III-Nitride and novel IV-Nitride epitaxy.

Research activities at Nanotech West span a range of cutting-edge materials research that is rather extraordinary for a single facility – from high-frequency GaN/AlGaN electronics, solar cells and infrared focal plane arrays, to microfluidics, biotechnology, and the fabrication of structures for use in the study of basic physics and chemistry. As the primary IMR location on Ohio State’s West Campus, Nanotech West provides substantial impact and continues to be a centerpiece of collaborative research to the university’s materials research community.
NANOTECH WEST LABORATORY FY18 HIGHLIGHTS

NTW supported more than 200 users from Ohio State, representing 69 principal investigators and 112 research projects in the Colleges of Engineering, Arts and Sciences, and Medicine. NTW supported 65 researchers from 22 institutions outside Ohio State, from industry and government to academia not affiliated with the university. NTW staff, aided by senior graduate student superusers and undergraduate engineering interns, trained 100 new users at the facility. More than one-fifth of those trainees came from outside Ohio State. John Carlin stepped into the role of NTW director after serving as associate director since 2012.

RESEARCH AND DEVELOPMENT HIGHLIGHT

Fabricating infrared (IR) detectors that operate without the need for cryogenic cooling is a goal for both commercial and security applications. Recently, NTW added a complement of IR materials growth, device fabrication and test capabilities. One project, Low Excess-Noise Avalanche Photodetectors with Superlattices (LEAPS), is utilizing these new resources to design and demonstrate the next generation of high-sensitivity IR detectors using III-V semiconductors in a superlattice configuration. The LEAPS team, comprised of four research institutions led by Professor Sanjay Krishna, has already demonstrated superlattice, IR avalanche photodetectors (APDs) grown via MBE at SEAL and fabricated and tested at NTW. Moving forward, the team will improve these single pixel APDs, and then demonstrate a LEAPS imager. LEAPS is funded by the Directed Energy Joint Technology Office in the Department of Defense.

PICTURED RIGHT: The design of a LEAPS single-pixel APD. Infrared light enters the Aperture and is detected by the Superlattice structure. The Top and Bottom contacts control and monitor the voltage and current. Image courtesy of Seunghyun Lee and Hyemin Jung.
The Center for Electron Microscopy and Analysis (CEMAS) boasts one of the largest concentrations of electron and ion beam analytical microscopy instruments in any North American institution, housed in a custom designed environment located on West Campus. The facility provides a world-class environment for five transmission electron microscopes (TEM), three scanning electron microscopes (SEM) and two dual-beam focused ion beam (FIB) instruments. The center’s two aberration corrected scanning transmission electron microscopes (S/TEM) include one instrument optimized for high spatial resolution imaging and analysis with the capability to provide sub-angstrom resolution, and a second instrument designed for investigation of soft materials and biomaterials with the ultimate in chemical analysis capabilities as well as high resolution imaging performance. Sample preparation laboratories for life sciences, physical sciences and engineering are provided with full technical support. The provision of comprehensive computer facilities for data processing and image simulation allows academic and industrial users to carry out their entire microscopy and analysis program at CEMAS.

CEMAS supported 204 Ohio State researchers and 16 users from external academic institutions and industry partners in FY18, while providing services for 33 external entities.
Significant updates and coming acquisitions of new laboratory equipment in FY2018 are set to bolster the already expansive facilities of CEMAS. Materials Science and Engineering professor David McComb and Electrical and Computer Engineering professor Paul Berger earned federal grants for laboratory equipment useful in advancing national defense research. One $1.425 million DURIP awarded to McComb, who serves as CEMAS director and IMR associate director, will enable the upgrade of a probe-corrected Titan scanning transmission electron microscope. Berger, also an IMR member, earned a $125,000 DURIP award to secure equipment, including a 110 GHz spectrum analyzer, which can perform high frequency and switching measurements of gallium nitride structures.

Additionally, CEMAS and the Air Force Research Laboratory (AFRL) established a long-term research collaboration platform for advanced materials characterization. The five-year $4.25 million grant will fund a cohort of post-doctoral research fellows (PDRFs) focused on precision measurement tools for advanced functional and structural materials characterization. The researcher fellows will embed in research groups at AFRL/RX offices at Wright-Patterson Air Force Base.

The implementation of new technology at CEMAS is also expanding its SEM capabilities. The facility installed two new Apreo FEG SEMs that have electrostatic and electromagnetic focusing lenses, helping achieve sub-nanometer resolutions, even on ferromagnetic samples. The SEMs can operate at voltages ranging from 30 kV, down to 200 V, and beam currents ranging from 1 pA, up to 400 nA. The new microscopes are also capable of stage-biasing from -4000 V to +600 V, reducing electron landing energies, and enabling analysis of non-conducting samples.

CEMAS also is set to house a new, state-of-the-art SEM, made possible by an $800,000 grant from the National Science Foundation and $340,000 in additional investment from Ohio State and the Ohio Department of Higher Education. The microscope will support a range of impactful research and teaching efforts at the university and throughout the state of Ohio. CEMAS director McComb, along with multiple departments and researchers within the College of Engineering and across the state, supported the grant.

Members of Girl Scouts of Ohio’s Heartland attending “Scoping Out Solar Energy” at the Nanotech West Lab and CEMAS explored the science behind sustainable energy through hands-on activities with College of Engineering volunteers. The Girl Scouts learned about energy use, conversion and storage, as well as energy consumption of electric vehicles. The topics complemented concepts learned in school and introduced them to new ideas regarding renewable energy and electron microscopy. Read more about the event on page 34.
NANOSYSTEMS LABORATORY

Physics Research Building First floor and Lower Level,
191 West Woodruff Avenue,
Columbus,
Ohio 43210

nsl.osu.edu
Contact: Dr. Denis V. Pelekhov,
Lab Manager
(614) 292-9125,
pelekhov.1@osu.edu
Dr. Camelia Selcu, in collaboration with the Professor Roberto Myers group, demonstrated the importance of using conductive atomic force microscopy (cAFM), a Bruker instrument at NSL, for quantifying the non-uniformities of current injection of different nanowire LED heterostructures at the nanoscale giving an insight on how they manifest in macroscopic devices. In other words, the results in the paper, “Nanoscale current uniformity and injection efficiency of nanowire light emitting diodes” (Appl. Phys. Lett. 112, 093107 [2018]) show the utility of cAFM to quantitatively probe the electrical inhomogeneities in as-grown nanowire ensembles without introducing uncertainty due to additional device processing steps, opening the door to more rapid development of nanowire ensemble-based photonics. Using same measurement techniques, in a different paper, “Nanoscale Electronic Conditioning for Improvement of Nanowire Light-Emitting-Diode Efficiency,” (ACS Nano 12, 3551 [2018]) the same collaboration implemented a straightforward method to mitigate the nonuniformities inherent to nanowire devices and boost their performance.
The Semiconductor Epitaxy and Analysis Laboratory (SEAL) is Ohio State’s primary facility for molecular beam epitaxy (MBE). It’s one of the largest MBE facilities in the U.S., fully staffed and open to university and industry researchers. SEAL includes six state-of-the-art MBE systems, each dedicated to different, complementary systems to ensure high-quality material epitaxy for basic studies and device development. Research focuses on a range of semiconductor materials, including III-V materials based on arsenides, phosphides, antimonides, nitrides, and advanced oxides, SiGe and 2-D materials. In FY18, SEAL provided $209k of research services that enabled more than $10M of external research funding to its facility and industrial clients. Several chambers are integrated into UHV cluster tools, enabling a range of hybrid structures and devices. Vacuum Cluster I encompasses two MBE chambers and an analytical system allowing III-V/IV integration studies and high-resolution X-ray photoelectron spectroscopy for in-situ chemical studies of pristine surfaces and interfaces. Cluster II is comprised of nitride- and oxide-MBE chambers, the combination of which also enables unique combinations of materials. SEAL has a range of advanced materials characterization tools to support breakthrough epitaxy and electronic materials.
• During FY18, SEAL added its sixth MBE system, which extends the SEAL family of MBE materials to AlGaInAsSb (or III-Sb) materials. The addition of III-Sb materials to SEAL’s existing range of materials means that SEAL can now produce materials and devices used for both narrow and wide bandgap electronics, and also photonics that can operate from the far infrared to the deep ultraviolet. The III-Sb MBE was enabled by the arrival of Prof. Sanjay Krishna, a leading expert in infrared photonics. SEAL welcomed Dr. Sen Mathews who has joined the SEAL technical staff to manage the daily operation of III-Sb MBE and train students.

• Research on the ultrawide bandgap semiconductor gallium oxide (Ga2O3) in SEAL grew dramatically in FY2018, thanks to several large programs awarded to two SEAL PIs, Professors Steve Ringel and Siddharth Rajan. Ringel leads a multi-university effort funded by the Defense Threat Reduction Agency (DTRA) and Rajan is the Ohio State lead PI for a recently awarded DoD Multidisciplinary University Research Initiative (MURI) on gallium oxide in a consortium led by UCSB and funded by the Air Force Office of Scientific Research (AFOSR). Both are five-year grants and support a wide range of other Ohio State and non-Ohio State faculty and students, including efforts at CEMAS and NTW.

Prof. Roland Kawakami and other researchers from the Kawakami Group in the Department of Physics demonstrated one of the world’s first room-temperature, two-dimensional ferromagnetic materials, MnSe2, using SEAL’s dedicated 2-D MBE system.

Magnetometry measurement at NanoSystems Laboratory shows that the ferromagnetic ordering in MnSe2 persist above room temperature, and structural characterization at CEMAS further confirms the magnetism is from the MnSe2. These exciting properties are promising for the development of next generation magnetic storage technology. The synthesis of two-dimensional magnetic materials at SEAL has created a foundation for a newly developing multi-university effort focused on exploring novel properties of two-dimensional magnetic materials that can be translated from fundamental physics to devices with novel properties.
The Institute for Materials Research welcomed several hundred professors, researchers and visitors to The Ohio State University for its 10th-annual OSU Materials Week, held May 8 through 11.

Each spring, students and researchers from within and outside academia around the world share their work at the IMR event. The goal is to encourage interdisciplinary collaboration and celebrate developments in materials-allied research.

“OSU Materials Week is a very special event, as it is both a technical conference in which researchers share the latest in innovative materials-allied research, and a celebration of Ohio State’s material community and all of its accomplishments,” said Steven Ringel, IMR Executive Director.

To help integrate new faculty into the materials-allied community, the event featured two days of “cross-cutting sessions” showcasing eight of the newest Materials and Manufacturing faculty members and their work. Three days of “focus sessions” allowed other faculty at Ohio State and researchers outside the university to share their work as well.

More than one hundred student researchers at Ohio State had a chance to shine during two popular competitions: the Three Minute Thesis (3MT®) and Poster Sessions.

The 2018 OSU Materials Week was supported by Ohio State Energy Partners (OSEP), a 50-50 joint venture between ENGIE and Axium Infrastructure; the Center for Emergent Materials, an NSF Materials Research Science and Emerging Center; and the Office of Energy and Environment.
KEYNOTE ADDRESS

“Materials for Bioresorbable Electronics”

John A. Rogers, Northwestern University

This year’s keynote address was given by renowned researcher John A. Rogers, a Northwestern University professor of Materials Science and Engineering, Biomedical Engineering, and Neurological Surgery, with several affiliate appointments. In the address, Rogers focused on his research of materials for bioresorbable electronics, being in the form of devices able to dissolve in water to yield completely benign end products. Enabled applications would push beyond the limits of what is possible with existing technologies, including zero-impact environmental monitors, “green” consumer electronics and bioresorbable biomedical implants. Rogers, who leads the Center for Bio-Integrated Electronics at Northwestern, has published more than 600 papers, is an inventor on more than 100 patents and applications, and co-founded several technology companies. His research has been recognized with numerous awards that include a MacArthur Fellowship, the Lemelson-MIT Prize, and the Smithsonian Award for American Ingenuity in the Physical Sciences.

THREE MINUTE THESIS (3MT®)

IMR kicked off its 10th-annual Materials Week conference with a Three Minute Thesis (3MT®) competition. Students were challenged to effectively communicate a distilled, compelling thesis and its significance in three minutes or less to hundreds of researchers from across the country and within the university. No props. No elaborate electronic media assistance. No dumbing it down. Presenters were allowed just one static slide to accompany their orations. 3MT finalists’ backgrounds ranged from Food, Agricultural and Biological Engineering to Physics. Brelon May won top prize for his clear and compelling thesis, “Flexible Ultraviolet LEDs on Metal.” May studies in the Department of Materials Science and Engineering with advisor Professor Roberto Myers. Aamena Parulkar was named runner-up for her thesis, “Enhancing Hydrophobicity of Catalysts.” Xianjie (Tony) Ren won people’s choice for his thesis, “Durability of Eggshell and Silica Filled Guayule Natural Rubber Composites.”
More than one hundred student and postdoctoral researchers at Ohio State came together to share their work in materials-allied fields with researchers from across the country during the two-day series of poster sessions at 2018 OSU Materials Week.

Researchers were allowed five minutes to present their research to small group of judges that roamed from poster to poster, then another five for a rapid-fire question-and-answer session.

The event allows undergraduate and graduate students an opportunity to share their work and receive feedback from professors and students of varying disciplines.

Ninety-five students were eligible to present. Their posters were judged on content, organization and overall clarity. Postdoctoral researchers also presented but were not eligible for awards.

Among the judges was IMR Associate Director Glenn Daehn, the Mars G. Fontana Professor in the Department of Materials Science and Engineering, who said he saw plenty of promising work on display as he walked through the rows of posters.

“What is really clear is that we are doing a lot of things here, at Ohio State, that will make a difference. And we’ve got great students going through,” Daehn said. “It’s been a privilege and a joy to judge these kids.”

Awards were presented to the Top 10 Student Poster presenters by Ohio State Executive Vice President and Provost Bruce McPherson.
Wayne D. Kaplan, professor in the Department of Materials Science and Engineering at Technion – Israel Institute of Technology, presented “The Influence of Fields and Dopants on Grain Boundary Mobility” to a captive Ohio State audience in October.

His talk dove deep into his research on the mobility of grain boundaries and how dopants and external fields influence the kinetics of grain growth.

The driving force for grain growth is thought to be understood, Kaplan said. However, less understood is the mechanism by which grain boundaries migrate, and how microscopic parameters affect grain boundary mobility.

The first part of his lecture addressed the concept of solute-drag, in which conventional wisdom indicates that moving a solute cloud with a grain boundary should either slow down grain boundary motion or not affect it.

The second part of the talk reviewed model experiments designed to probe the influence of external fields on grain boundary mobility.

At the Technion in Haifa, Israel, Kaplan holds the Karl Stoll Chair in Advanced Materials and serves as the Executive Vice President for Research at the science and technology research university.

Robert M. Wallace, of the University of Texas at Dallas, brought decades of experience in the fields of physics and materials science to students and faculty at Ohio State on March 27 with his lecture “High-K Dielectrics: A Perspective on Applications from Silicon to 2-D Materials.”

Wallace is a renowned professor of Materials Science and Engineering and Erik Jonsson Distinguished Chair in the School of Engineering and Computer Science at UT Dallas.

His presentation walked attendees through evolutions and challenges in gate-dielectrics research, from the establishment of Hf-based dielectrics in commercial silicon technology fabrication processes to pushing the limits of channel scaling with atomically thin 2-D materials.

“I wanted to try to give a larger perspective of how important materials are and how important interdisciplinary interactions are in doing this kind of work,” Wallace said.

Reviewing some of the physical characteristic techniques he utilizes, Wallace explained how his research group applies them to high-mobility electronic materials, like the arsenides and nitrides, for example. The latter half of the lecture focused on his more recent work with 2-D materials and interfaces.
THE SPIN CALORITRONICS IX CONFERENCE

Scientists from all over the world interested in the study of thermally driven spin fluxes came together this year for the Spin Caloritronics IX Conference at The Ohio State University. Spin caloritronics is a subset of the general study of spin and magnetization dynamics, covering time-dependent, spin-based phenomena and properties, such as spin transport, that are out of thermodynamic equilibrium. The conference focused on thermal spin transport, and showcased new results in the fields of spin transport and spin dynamics, in general.

More than 50 external attendees and speakers joined 32 participants from Ohio State for the five-day conference at the Physics Research Building to discuss new discoveries and future research prospects for the coming decade. Topics discussed included thermal spin transport, including the spin-seebeck effect, magnon-drag and magnon-phonon interactions; collective spin modes and macroscopic effects, including thermally-driven macroscopic dynamics, other macroscopic dynamics, condensation and magnon Bose-Einstein condensation; topological effects and Weyl points, including magnons and electrons; spin currents through antiferromagnets; chiral structures, including Dzyaloshinskii-Moriya interaction, thermal Hall effects, and skyrmions and heat-induced skyrmion dynamics; and magnetization dynamics, including insulators and metals.

This workshop was supported by the CEM, an NSF MRSEC; Army Research Office; the College of Engineering; the Institute for Materials Research; the Office of Energy and Environment; and the Department of Mechanical and Aerospace Engineering. The event was organized by CEM executive committee member Joseph Hermans, professor in the Department of Mechanical and Aerospace Engineering, and CEM director P. Chris Hammel, professor in the Department of Physics.
Hundreds of materials experts from around the world came together at The Ohio State University for the 18th International Conference on the Strength of Materials (ICSMA), marking it just the third time the gathering has been held in the U.S. in its 50-year history. ICSMA fosters inspiration and community with a focus on understanding the fundamental phenomena controlling strength and other mechanical properties of materials.

Peter Anderson, professor and chair of the Department of Materials Science and Engineering (MSE) at Ohio State, served as a program coordinator this year, welcoming international colleagues to the IMR-supported event at the Ohio Union’s Archie Griffin Ballroom. The five-day event showcased 14 symposia, eight plenary talks, more than 50 invited and 250 contributed talks, as well as two days of poster sessions. Three student poster winners were awarded for their compelling research presentations: Caryln LaRosa, a graduate student in MSE at Ohio State; John Steinbeck, from the University of Connecticut; and Mike Schneider, from the Ruhr-Universität Bochum in Germany.

Along with the younger researchers, renowned investigators Haël Mughrabi and John Hirth were celebrated at ICSMA18 for their contributions in the field of materials science. The event also reunited Hirth and Anderson, who co-authored “Theory of Dislocations” with Norwegian physicist Jens Lothe. Hirth and Anderson signed copies of the in-demand third edition of the text at the event.
GIRL SCOUTS JOIN OHIO STATE ENGINEERS FOR SUSTAINABLE ENERGY EVENT

Members of the Girl Scouts of Ohio’s Heartland attending the first “Scoping Out Solar Energy” in March explored the science behind sustainable energy with engineering staff and students at IMR’s Innovation Lab and the Center for Electron Microscopy and Analysis.

About 20 Girl Scouts spent the day with College of Engineering volunteers, taking part in discussions and hands-on science and technology activities complementing concepts learned in school and introducing them to new ideas about renewable energy and electron microscopy.

Through each activity, the elementary school-aged girls also had an opportunity to consider their potential roles as science and engineering leaders in the future. Vicky Doan-Nguyen, an assistant professor in the departments of Materials Science and Engineering and Mechanical and Aerospace Engineering who was hired through the IMR-operated M&MS Discovery Themes focus area, led the program at Ohio State and coordinated activities with Girl Scouts of Ohio’s Heartland.
Four undergraduate students stepped up their advocacy for the further cultivation of a student-led entrepreneurship and innovation culture at Ohio State.

Liyang Feng, Juan Tramontin, George Valcarcel and Kai Vogeler were named University Innovation Fellows (UIF) by Stanford University’s Hasso Plattner Institute of Design in fiscal year 2018. The global program aims to increase campus innovation, entrepreneurship, creativity and design thinking through the empowerment of student leaders.

The fellows work within institutions of higher education to improve peers’ innovation skills and outlooks, helping them prepare for the competitiveness of an ever-evolving economy. To help do this, the students collaborate with faculty in the development of new programs, design innovation spaces and plan learning events, among other activities.

The group, with majors ranging from logistics management to computer science, industrial systems and mechanical engineering, attended the UIF Silicon Valley Meetup for several days of innovation workshops and immersive training activities, plus collaboration with peers and leaders in academia and industry. The program has trained more than 1,200 students, ranging from undergraduate to doctoral, at 216 schools around the world.

IMR Innovation Director Jay Sayre serves as a faculty advisor to the group, along with Peter Rogers, clinical professor in the Department of Engineering Education. Earlier in the academic year, the students launched IRIS, an Ohio State student organization fostering collaborative approaches to problem solving.
IMR HAS SEEN A 14:1 RETURN ON INVESTMENT
IN ITS FIRST 11 YEARS OF OPERATIONS, FY2007-2018
IMR Members’ External Funding
Sponsored projects with awarded budgets

SPONSORED PROJECTS
$365.2M

NEW AWARDS
$86.3M

EXPENDITURES ON SPONSORED PROJECTS:
$73.4M

Figures provided by the Office of Sponsored Programs
Anant Agarwal, Professor, Electrical and Computer Engineering
Gunjan Agarwal, Assistant Professor, Biomedical Engineering
Sudha Agarwal, Professor, Oral Biology
Sheikh Akbar, Professor, Materials Science and Engineering
Boian Alexandrov, Research Associate Professor, Materials Science and Engineering
Heather Allen, Professor, Chemistry and Biochemistry
Douglas Aldorf, Associate Professor, Earth Sciences
Peter Anderson, Professor, Materials Science and Engineering
Betty Lise Anderson, Professor, Electrical and Computer Engineering
Shamsul Araf, Assistant Professor, Electrical and Computer Engineering
Aaron Arehart, Research Assistant Professor, Electrical and Computer Engineering
Aravind Asthagiri, Associate Professor, Chemical and Biomolecular Engineering
Jovica Badjic, Associate Professor, Chemistry and Biochemistry
Thomas Gramila, Associate Professor, Mechanical and Aerospace Engineering
Karen Dannemiller, Associate Professor, Chemical and Biomolecular Engineering
Rafael Bruschweiler, Professor, Chemistry and Biochemistry
Rudy Buchheit, Professor, Associate Dean, Materials Science and Engineering; Fontana Corrosion Center
Ralf Bundschuh, Associate Professor, Physics
Lisa Burris, Assistant Professor, Civil, Environmental Engineering and Geodetic Sciences
Richard Busick, Senior Lecturer, Engineering Education Innovation Center
Michael Camp, Assistant Professor, Fisher College of Business
Lei (Raymond) Cao, Assistant Professor, Mechanical and Aerospace Engineering
William Carson, Professor, Surgery Oncology
Jose Castro, Professor, Mechanical and Aerospace Engineering; Center for Advanced Polymer and Composite Engineering
Carlos Castro, Assistant Professor, Mechanical and Aerospace Engineering
Jeffrey Chalmers, Professor, Chemical and Biomolecular Engineering
Heather Chandler, Assistant Professor, Optometry
Hanna Cho, Assistant Professor, Mechanical and Aerospace Engineering
William Clay, Professor, Materials Science and Engineering
John Clay, Associate Professor, Chemical and Biomolecular Engineering
Anne Co, Assistant Professor, Chemistry and Biochemistry
James Coe, Professor, Chemistry and Biochemistry
Edward Collings, Professor, Materials Science and Engineering
Terry Conilk, Assistant Professor, Mechanical and Aerospace Engineering
Stuart Cooper, Professor, Chemical and Biomolecular Engineering
Katrina Cornish, Professor, Horticulture and Crop Science
Glenn Daehn, Professor, Materials Science and Engineering
Karen Dannemiller, Assistant Professor, Civil, Environmental Engineering and Geodetic Sciences
Marcelo Dapino, Associate Professor, Mechanical and Aerospace Engineering
Lakshmi Dasi, Associate Professor, Surgery; Biomedical Engineering
Frank De Lucia, Distinguished University Professor, Physics
David Dean, Associate Professor, Plastic Surgery
Vicky Doan-Nguyen, Assistant Professor, Materials Science and Engineering
Sulliman Dregia, Associate Professor, Materials Science and Engineering
Charles Drummond, Associate Professor, Materials Science and Engineering
Rebecca Duplaix, Associate Professor, Mechanical and Aerospace Engineering
Prabir Dutta Fox, Professor, Chemistry and Biochemistry
Arthur Epstein, Distinguished University Professor, Physics
Thaddeus Ezeji, Assistant Professor, Animal Sciences
Liang-Shih Fan, Distinguished University Professor, Chemical and Biomolecular Engineering
Dave Farson, Associate Professor, Materials Science and Engineering
Ayman Fayed, Associate Professor, Electrical and Computer Engineering
Carolin Fink, Assistant Professor, Materials Science and Engineering
Gerald Frankel, Professor, Materials Science and Engineering
Hamish Fraser, Professor, Materials Science Engineering
Samir Ghadiali, Associate Professor, Biomedical Engineering
Nima Ghahremane, Research Scientist, Electroscience Laboratory
Maryam Ghazisaeidi, Assistant Professor, Materials Science Engineering; Physics
Josh Goldman, Assistant Professor, Chemistry and Biochemistry
Keith Gooch, Associate Professor, Biomedical Engineering
Pelagia-Iren Gouma, Orton Jr. Chair; Professor, Materials Science and Engineering
Thomas Gramila, Associate Professor, Physics
Tyler Grassman, Professor, Electrical and Computer Engineering
Jianjun Guan, Assistant Professor, Materials Science and Engineering
Yann Guenezec, Professor, Mechanical and Aerospace Engineering
Liang Guo, Assistant Professor, Electrical and Computer Engineering
Prabhat Gupta, Professor, Materials Science and Engineering
Jay Gupta, Assistant Professor, Physics
Terry Gustafson, Associate Professor, Chemistry and Biochemistry
Denis Guttridge, Professor, Cancer Biology and Genetics
Lisa Hall, Assistant Professor, Chemical and Biomolecular Engineering
Nathan Hall, Assistant Professor, Radiology
P. Chris Hammel, Director, Center for Emergent Materials
Derek Hansford, Associate Professor, Biomedical Engineering
Ryan Harne, Assistant Professor, Mechanical and Aerospace Engineering
Richard Hart, Chair, Biomedical Engineering
Andrew Heckler, Associate Professor, Physics
Joseph Heremans, Professor, Ohio Eminent Scholar, Mechanical and Aerospace Engineering
Anton Heyns, Lecturer, Chemistry and Biochemistry
Ned Hill, Professor, Public Affairs
George Hinkle, Professor Emeritus, Pharmacy
W.S. Winston Ho, Professor, Chemical and Biomolecular Engineering
John Horack, Professor, Mechanical and Aerospace Engineering
Nan Hu, Assistant Professor, Civil, Environmental and Geodetic Engineering
Jinwoo Hwang, Assistant Professor, Materials Science and Engineering
Joerg Jinschek, Associate Professor, Materials Science and Engineering
Ezekiel Johnston-Halperin, Assistant Professor, Physics
Roland Kawakami, Professor, Physics
Mарат Khafizov, Assistant Professor, Mechanical and Aerospace Engineering
Waleed Khalil, Assistant Professor, Electrical and Computer Engineering
Jung-Hyun Kim, Assistant Professor, Mechanical and Aerospace Engineering
Matt Kleinhenz, Associate Professor, Horticulture and Crop Science
Kurt Koelling, Professor, Chemical and Biomolecular Engineering
Sanjay Krishna, Professor, Electrical and Computer Engineering
Ashok Krishnamurthy, Associate Professor, Electrical and Computer Engineering
Gregory Lafyatis, Associate Professor, Physics
John Lannutti, Associate Professor, Materials Science and Engineering
Jeanie (ChunNing) Lau, Professor, Physics
Robert J. Lee, Professor, Pharmacy
Robert Lee, Chair, Electrical and Computer Engineering
Stephen Lee, Associate Professor, Biomedical Engineering
L. James Lee, Professor, Chemical and Biomolecular Engineering
Jennifer Leigh, Assistant Professor, Biomedical Engineering
John Lenhart, Associate Professor, Civil, Environmental Engineering and Geodetic Sciences
Blaine Lilly, Associate Professor, Chemical and Aerospace Engineering
Li-Chiang Lin, Assistant Professor, Chemical and Biomolecular Engineering
John Lippold, Professor, Materials Science and Engineering
Jun Liu, Professor, Biomedical Engineering
Xun Liu, Assistant Professor, Materials Science and Engineering
Ned Hill, Professor, Public Affairs
George Hinkle, Professor Emeritus, Pharmacy
W.S. Winston Ho, Professor, Chemical and Biomolecular Engineering
John Horack, Professor, Mechanical and Aerospace Engineering
Nan Hu, Assistant Professor, Civil, Environmental and Geodetic Engineering
Jinwoo Hwang, Assistant Professor, Materials Science and Engineering
Joerg Jinschek, Associate Professor, Materials Science and Engineering
Ezekiel Johnston-Halperin, Assistant Professor, Physics
Roland Kawakami, Professor, Physics
Mарат Khafizov, Assistant Professor, Mechanical and Aerospace Engineering
Waleed Khalil, Assistant Professor, Electrical and Computer Engineering
Jung-Hyun Kim, Assistant Professor, Mechanical and Aerospace Engineering
Matt Kleinhenz, Associate Professor, Horticulture and Crop Science
Kurt Koelling, Professor, Chemical and Biomolecular Engineering
Sanjay Krishna, Professor, Electrical and Computer Engineering
Ashok Krishnamurthy, Associate Professor, Electrical and Computer Engineering
Gregory Lafyatis, Associate Professor, Physics
John Lannutti, Associate Professor, Materials Science and Engineering
Jeanie (ChunNing) Lau, Professor, Physics
Robert J. Lee, Professor, Pharmacy
Robert Lee, Chair, Electrical and Computer Engineering
Stephen Lee, Associate Professor, Biomedical Engineering
L. James Lee, Professor, Chemical and Biomolecular Engineering
Jennifer Leigh, Assistant Professor, Biomedical Engineering
John Lenhart, Associate Professor, Civil, Environmental Engineering and Geodetic Sciences
Blaine Lilly, Associate Professor, Chemical and Aerospace Engineering
Li-Chiang Lin, Assistant Professor, Chemical and Biomolecular Engineering
John Lippold, Professor, Materials Science and Engineering
Jun Liu, Professor, Biomedical Engineering
Xun Liu, Assistant Professor, Materials Science and Engineering
Ned Hill, Professor, Public Affairs
George Hinkle, Professor Emeritus, Pharmacy
W.S. Winston Ho, Professor, Chemical and Biomolecular Engineering
John Horack, Professor, Mechanical and Aerospace Engineering
Nan Hu, Assistant Professor, Civil, Environmental and Geodetic Engineering
Jinwoo Hwang, Assistant Professor, Materials Science and Engineering
Joerg Jinschek, Associate Professor, Materials Science and Engineering
Ezekiel Johnston-Halperin, Assistant Professor, Physics
Roland Kawakami, Professor, Physics
## DIRECTORS

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steven A. Ringel</td>
<td>Distinguished University Professor, Professor of Electrical Engineering, Associate Vice President for Research, Executive Director, Institute for Materials Research</td>
</tr>
<tr>
<td>Neal A. Smith</td>
<td>Professor of Electrical Engineering</td>
</tr>
<tr>
<td>Jay R. Sayre</td>
<td>Assistant Vice President, Director of Innovation</td>
</tr>
</tbody>
</table>

## ASSOCIATE DIRECTORS

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glenn Daehn</td>
<td>Associate Director, Manufacturing Initiatives, Fontana Professor, Materials Science and Engineering</td>
</tr>
<tr>
<td>David McComb</td>
<td>Associate Director, West Campus Professor and Ohio Research Scholar, Materials Science and Engineering</td>
</tr>
<tr>
<td>Fengyuan Yang</td>
<td>Associate Director, Seed Grants Professor, Physics</td>
</tr>
</tbody>
</table>

## M&MS CLUSTER AREA LEADS

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glenn Daehn</td>
<td>Smart Structures, M&amp;MS Cluster Area, Fontana Professor, Materials Science and Engineering</td>
</tr>
<tr>
<td>Sanjay Krishna</td>
<td>Low-energy Devices, M&amp;MS Cluster Area, George R. Smith Chair in Engineering Professor, Electrical and Computer Engineering</td>
</tr>
<tr>
<td>Yiying Wu</td>
<td>Energy Storage, M&amp;MS Cluster Area, Professor and Leet Chair, Chemistry and Biochemistry</td>
</tr>
</tbody>
</table>

## OPERATIONS STAFF

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angela Dockery</td>
<td>IMR Business Manager</td>
</tr>
<tr>
<td>Jennifer Donovan</td>
<td>Executive Assistant to Prof. Steven Ringel</td>
</tr>
<tr>
<td>Joanna Gardner</td>
<td>IMR Administrator and Grants Developer</td>
</tr>
<tr>
<td>Ryan Horns</td>
<td>ECE and IMR Communications Specialist</td>
</tr>
<tr>
<td>Mike Huson</td>
<td>IMR Public Relations Coordinator</td>
</tr>
<tr>
<td>Kari Roth</td>
<td>Innovation Manager</td>
</tr>
</tbody>
</table>

---

[Contact Information: (614) 292-6904, info@osu.edu]
WE GRATEFULLY ACKNOWLEDGE THE FOLLOWING CONTRIBUTORS WHO PROVIDED VALUABLE CONTENT TO THIS REPORT:

Nate Ames, Associate Director and Engineering Manager, Center for Design and Manufacturing Excellence
John Bair, Executive Director, Center for Design and Manufacturing Excellence
FuWaye Bender, Data Services Specialist, Office of Economic and Corporate Engagement
Mark Brenner, Senior Research Associate, Semiconductor Epitaxy and Analysis Laboratory
John Carlin, Director, Nanotech West Laboratory
Henk Colijn, Assistant Director, Research Operations, Center for Electron Microscopy and Analysis
Susan Conrad, Associate Director, Office of Sponsored Programs
Elizabeth Culley, MEP Marketing and Outreach Coordinator, Communication and Marketing Coordinator, Center for Design and Manufacturing Excellence
Vicky Doan-Nguyen, Assistant Professor, Department of Materials Science and Engineering, Department of Mechanical and Aerospace Engineering
Jay Gupta, Associate Professor, Department of Physics
Ned Hill, Professor, Knowlton School of Architecture and John Glenn Dean's Office
ideastream.org
Kathryn Kelley, Executive Director, Ohio Manufacturing Institute
Rachel Page, Program Coordinator, Center for Emergent Materials
Denis Pelekhov, Director, NanoSystems Laboratory
Mohit Randeria, Professor, Department of Physics
Matt Schutte, Director of Communications, College of Engineering
Camelia Selcu, Research Associate NanoSystems Laboratory
Ashley Swartz, Program Manager, Center for Electron Microscopy and Analysis

© 2018 All rights reserved.