Materials Research Laboratory

The Materials Research Laboratory (MRL) was founded in October 2017 through a merger of the Materials Processing Center (MPC) and the Center for Materials Science and Engineering (CMSE). Together, these centers have served more than 150 faculty and their research groups and the broad MIT materials research community for over 38 years. By combining the expertise and activities of these centers, MRL enables research that benefits society, helps companies and federal agencies address fundamental challenges, creates opportunities for technology transfer and practical engineering applications, and encourages collaboration through interdisciplinary research groups, shared experimental facilities, and educational outreach programs.

MRL encompasses research that includes energy conversion and storage, quantum materials, spintronics, photonics, metals, integrated microsystems, materials sustainability, solid-state ionics, complex oxide electronic properties, biogels, and functional fibers. These are all interdisciplinary topics in materials. Each topic plays a critical role with the focus on scientific discovery, and how to design and make materials that lead to systems that have improved performance or that enable new approaches to existing problems.

MRL also encourages interactions with industry through collaborative research and exchanges with visiting scientists, industrial internships, and educational opportunities. New interactions with industry include MRL support of faculty engagement with four of the 14 US Manufacturing Innovation Institutes. MRL sponsors a major annual workshop on topical areas of materials research involving both students and faculty. The Materials Day symposium and student poster session is held each fall with invitations to members of industry and the community.

External Advisory Board

The MRL External Advisory Board (EAB) whose members come from industry, government, and academia, provide valuable advice on program development and management. They also assist in identifying opportunities for interactions with industry. The EAB meets for a full day after the Materials Day event each year. There are presentations by members of the Institute's leadership on new research initiatives and the MRL director and staff report on the prior year's activities and present on planned initiatives and goals for subsequent years. In addition, several new faculty present their planned research at MIT and senior faculty discuss major new initiatives. Faculty members who spoke at this year's board meeting included: Professor and Associate Provost Krystyn Van Vliet (Materials Science and Engineering [DMSE]), Professor and Associate Provost Karen Gleason (Chemical Engineering [ChemE]), Professor Vladimir Bulović (Associate Dean for Innovation), Professor Elsa Olivetti (DMSE), Professor Raymond Ashoori (Physics), and Professor Katharina Ribbeck (Biological Engineering).

The board meeting culminates in an oral and written report to the vice president for research or a designated representative. Current board members represent 3M Corporate Research Laboratory, American Lightweight Materials Manufacturing Innovation Institute, Applied Materials, Gateway for Accelerated Innovation in Nuclear, General Motors, IBM, Harvard University, Lockheed Martin Space Systems, Lord Corporation, Pellion

Technologies, Saint-Gobbain High Performance Materials, Sandia National Laboratories, Semiconductor Research Corporation, The Boeing Company, and the wTe Corporation.

Internal Advisory Board

The MRL Internal Advisory Board (IAB) is comprised of faculty from across the Institute with a shared interest in materials research and collaboration with other leading departments, laboratories, and centers. The IAB members include Professors Antoine Allanore, Raymond Ashoori, Vladimir Bulović, Peter Fisher, Gene Fitzgerald, Gleason, Lionel Kimerling, Elsa Olivetti, Katharina Ribbeck, Don Sadoway, Chris Schuh, and Harry Tuller. Members represent research communities from the Departments of Materials Science and Engineering (DMSE), Physics, Electrical Engineering and Computer Science (EECS), Biological Engineering, and Chemical Engineering (ChemE), as well as the Office of the Provost and MIT.nano. The IAB members serve a critical role in helping MRL leadership identify key goals for the laboratory and methods of achieving these goals. The top three goals for MRL include: strengthening interdisciplinary research leveraging the National Science Foundation's Materials Research Science and Engineering Center (NSF MRSEC) program model and engaging with industry; developing new capabilities and toolsets for the research community; and community building.

Materials Research Science and Engineering Center

The MRL MRSEC at MIT, funded by the NSF, was established in 1994 as the core program of the CMSE. In November 2014, the NSF renewed a six-year $16.2 million MRSEC center grant to fund research and educational outreach programs as well as its shared experimental facilities from November 2014 to October 2020. This award was the culmination of an extensive two-year internal and external review process and proposal preparation which enabled CMSE to compete with over 150 other national institutions to win one of 12 NSF MRSEC center awards for this six-year period.

During academic year 2018, the MRL MRSEC research portfolio included three Interdisciplinary Research Groups (IRGs), and five single investigator seed projects. The MRSEC grant supports 27 faculty from nine MIT departments and one faculty member through a University of Central Florida sub-award. FY2018 research highlights include:

IRG-I: Harnessing In-fiber Fluid Instabilities for Scalable and Universal Multidimensional Nanosphere Design, Manufacturing, and Applications; PI's: Polina Anikeeva (co-lead); Marin Soljačic (co-lead); Yoel Fink; John Joannopoulos; Steven Johnson; and Ayman Abouraddy (University of Central Florida).

IRG-I explores multi-material in-fiber fluid instabilities and uses the resultant knowledge to develop a new materials-agnostic fabrication approach for the creation of nanoparticles of arbitrary size, geometry, and composition. This work enables wide-ranging applications, including opto-electronics, neuronal interfaces, and metamaterials design. In one example, they fabricated monodisperse microspheres comprised of an organic matrix embedded with uniformly distributed high-index inorganic nanoparticles. Such particles can be used in optical coatings and paints with tailorable scattering characteristics. The team also fabricated pixelated light-emitting fibers consisting of regularly spaced particles acting as discrete activation

sites for light emission from an electroluminescent core. They further demonstrated 3D placement using printable filaments, making the process applicable to 3D displays and potentially enabling other 3D electronics applications. Finally, the team is developing multifunctional fiber-based nerve guidance scaffolds for probing and interrogating neural activity during repair following nerve injury.

IRG-II: Simple Engineered Biological Motifs for Complex Hydrogel Function; PI's: Katharina Ribbeck (co-lead); Bradley Olsen (co-lead); Patrick Doyle; Alan Grodzinsky; Paula Hammond; Niels Holten-Andersen; Jeremiah Johnson; Timothy Lu; and Gareth McKinley.

IRG-II research seeks fundamental insight into molecular mechanisms that govern structure-property relationships of complex biological hydrogels, and to use this knowledge to create synthetic mimics with similar extraordinary properties. Hydrogels play important roles as selective permeability barriers in biological systems. This IRG discovered a mechanism to explain the paradoxical observation that in certain hydrogels, strongly-binding particles diffuse through the gel while nonbinding particles are permanently trapped. This understanding has led to design rules for engineering complex selective gels. Using electrically-charged engineered nanoparticles, they also discovered the key role that surface charge distributions play in protein transport through cartilage—an important biological hydrogel. This may provide new means to enhance drug delivery through tissues to treat diseases such as osteoarthritis. Finally, the team developed new metrology techniques and modeling that answered important open questions regarding crosslinking networks in gels, yielding key insights into associative polymer design.

IRG-III: Nanoionics at the Interface: Charge, Phonon, and Spin Transport; PI's: Caroline Ross (co-lead); Bilge Yildiz (co-lead); Geoffrey Beach; Gang Chen; Harry Tuller; and Krystyn Van Vliet.

IRG-III research seeks to discover the coupling mechanisms between oxygen defects and the transport of phonons—spin and charge at the interfaces of metal oxides. The group developed a thermodynamic model formulation to quantify point defect formation energetics under high electric fields. This insight explains experimental results that conventional models cannot—providing a new tool to predict and to design materials in which vacancies can be engineered and dynamically manipulated. The team has also used electrochemical tuning to systematically investigate the oxygen-pumping-enabled metal-to-insulator transition that they recently discovered in VO_2. This material is of great interest owing to the possibility of achieving electrically-switched resistance states for memory and neuromorphic computing applications. Finally, the team designed material heterostructures in which solid-state pumping of O^{2-} and H^{+} ions allows for electric field gating of thermal conductivity and magnetic properties, potentially enabling device applications such as thermal switches and solid-state magnetic memories and logic devices.

Seed Projects

Direct Deposition of Catalysts on Porous Metallic Foams for Efficient CO2 Electroreduction; PI: Fikile Brushett
This seed examines nanoparticle-catalyzed heterogeneous CO2 electroreduction for use in gas-to-hydrocarbon synthesis. Recent results show that deposition of Au and

Ag nanoparticles onto carbon black—which is subsequently deposited onto porous gas diffusion electrodes—leads to high CO:H2 selectivity with long-term stability. Ongoing work aims to understand and mitigate electrode activity fading, and to directly deposit electrocatalysts to form nanoporous electrode layers.

Thin Film Chromium Oxide Perovskites; PI: Riccardo Comin
This project explores correlated spin physics in a new family of chromium-based perovskites. Seed research has achieved $Sr_{2-x}La_xCrO_4$ thin-film growth in the Ruddlesden-Popper perovskite structure and revealed spin-density-waves persisting up to around 250K, which is unexpected and unprecedented. Ongoing research includes electronic band structure mapping and synthesis of materials with similar chemistry but different dimensionality.

Room Temperature Spin-orbit Torque Switching Induced by a Topological Insulator; PI: Luqiao Liu
The goal of this project is to understand spin transport in ferromagnet/topological-insulator (TI) heterostructures, mediated by topologically protected electronic surface states. Key results include demonstration of room-temperature current-induced magnetization switching mediated by a giant spin Hall effect at the interface between a magnetic CoTb alloy and the prototypical TI material Bi_2Se_3. The high switching efficiency could enable low-power spin-based electronics.

Bottlebrush Hydrogels as Tunable Tissue Engineering Scaffolds; PI: Robert Macfarlane
This seed aims to engineer hydrogel-based tissue scaffolds using bottlebrush polymers (BBPs) with unique design features. The required biocompatibility and biochemical functionality limit the choice of polymer building blocks, hindering property optimization. This project successfully synthesized a new BBP-based hydrogel with superior porosity and stiffness through coacervate formation of oppositely charged polymer brush ends that lead to network formation in solution.

A Lithium Solid-State Memristor—Modulating Interfaces and Defects for Novel Li-Ionic Operated Memory and Computing Architectures; PI: Jennifer Rupp
This project investigates Li-ion transport and defect kinetics in oxides to design memristor materials for synaptic computing. Memristors operate via ion hopping in oxides, but despite their fast diffusivity high-electric-field stability, solid-state Li-ion conductors have been largely neglected as resistance switching materials. This work synthesized and optimized Li-oxide films that exhibit large bipolar resistive switching, establishing Li-based oxides as alternative memristor materials.

Center for Integrated Quantum Materials

The Center for Integrated Quantum Materials (CIQM) is an NSF Science-Technology Center (STC) led by Harvard University, with principal partners at MIT; the Museum of Science, Boston; and Howard University. Now in its fifth year, CIQM focuses on discovering "Extraordinary new quantum materials [that] enable atomic-scale electronics and photonics that transform signal processing and computation." MIT's CIQM effort pulls together 10 PI's from the physics department and EECS working in the various fields of Quantum Materials by Design, Quantum Electronics and Photonics, Universal Quantum Interface, and Atomic Scale Networks. The new family

of quantum materials being explored includes graphene, hexagonal boron nitride, and molybdenum disulfide and nitrogen vacancy centers in diamond, among others for their unusual electronic, optical, and magnetic properties. The interest in these materials has potential uses for sensing, information processing, and memory applications. Support is provided to seven graduate students, five postdoctoral associates, and undergraduate students from MIT. Additionally, graduate students are involved in exchange programs throughout the network of partner institutions. The NSF has renewed the CIQM program for an additional five-year period.

Quantum Science Summer School

The NSF and Department of Energy (DOE) Quantum Science Summer School (QS^3) is a four-year program with the mission of training graduate students and postdocs in the fields of condensed matter physics, materials science, and disciplines of quantum science in engineering, chemistry, and related fields. NSF solely funded the first year but it's expected that DOE will also contribute in future years, with a total funding of $1M.

The annual summer school focuses on key topics of interest in quantum science and their applications to new technologies in academic and industrial contexts. The goal is to provide expert training to participants in these subfields by experts in the field in an intensive two-week format. The June 10–22, 2018 school held at Cornell University was focused on fundamental and applications of quantum science. The program organizers include Assistant Professor Joe Checkelsky (MIT), Associate Professor Natalia Drichko (John's Hopkins University), Associate Professor Liang Fu (MIT), Assistant Professor Kyle Shen (Cornell University), and Associate Professor Jun Zhu (Penn State University). Over 180 students applied for the program, of those, 56 were accepted. The program covered student expenses, including travel, housing, and meals.

Microphotonics Center

The Microphotonics Center (MPhC) was established in 1999 to support research on silicon photonic device integration and applications to support the demand for exponential growth in the communication bandwidth that has enabled the information age. The MPhC performs research and technology supply chain studies utilizing a technology working group (TWG) model. The center's Industrial Advisory Board commissions working groups that operate with members and allied industrial partners from around the world. These studies were originally incorporated in official releases of the MIT Communication Technology Roadmap (CTR). In addition to regular meetings of the MPhC Board and TWGs, the center membership meets twice each year to review the progress of the TWGs and decide on new initiatives.

In 2014, the National Institute of Standards and Technology in collaboration with the International Electronics Manufacturing Initiative (iNEMI) funded a program to expand the MPhC CTR effort. The combined organizations broadened the topics of roadmap activity to include areas critical to manufacturing integrated electronic-photonic technology and its supply chain. The result was the establishment of a new global industry roadmap titled the Integrated Photonics System Roadmap International with new technology working groups established to address design, system integration, packaging, test requirements, and test opportunities.

The Manufacturing USA® Integrated Photonics Institute for Manufacturing Innovation (IP-IMI) was awarded to American Institute for Manufacturing (AIM) Photonics in Rochester, NY, on July 27, 2015. This award has provided continued support of the MPhC manufacturing roadmap activities. Additional TWGs have been established through project awards with the AIM Photonics Institute including Electronic-Photonic Design, Analog Radio Frequency (RF) Systems, and Sensors.

In addition to its coordination of efforts with the AIM Photonics Institute, the center continues to maintain excellent and growing representation and participation from companies and organizations from around the world. The center's roadmap activities address the larger supply chain challenges of the industry, beyond silicon-based integrated photonics for network communications systems. New areas for the center include the use of photonic technology for RF, free space applications such as lidar, consumer electronics, as well as others related to imaging and sensing.

American Institute for Manufacturing Integrated Photonics

AIM Photonics is funded by a five-year $110 million federal investment combined with a $500M industry-state cost share commitment. The public-private partnership is designed to help strengthen US-based high-tech manufacturing. AIM Photonics brings government, industry, and academia together to advance domestic capabilities in integrated photonic technology. The lead institution of this partnership is the State University of New York Polytechnic Institute (SUNY Poly). The executive management team of AIM Photonics includes Associate Professor Michael Watts as chief technology officer and Professor Kimerling in the position of Education, Workforce Development and Roadmap executive as well as lead PI for MIT when collaborating with AIM Photonics. It is now in its third year of operation with MRL's support on proposals and administration of specific program award activities involving MIT faculty.

The AIM Photonics Academy has been established under the leadership of Professor Kimerling as an organization based at MIT leading the development of education, workforce development, and roadmap content and services addressing manufacturing technology issues for the integrated photonics industry. Funding of its activities are supported by project awards approved through the AIM Photonics annual call for proposals. The Academy is also adding programs that are directly funded by participants as it looks to build a sustainable program beyond the federally funded period. The academy leadership team includes participating members from iNEMI, University California at Santa Barbara, SUNY Poly, University of Rochester (UR), Rochester Institute of Technology (RIT), Boston University (BU), and University of Arizona.

The core education and workforce development content includes multiple education modules, teaching packages, and videos that are hosted on the Academy website, which also has educational programs including the highly successful week-long summer and winter academy events first held at MIT in July and December 2017. In addition, there are webinars and roadmap meetings with members and invited guests. The Academy is leveraging online education platforms—such as MITx and TED-Ed—to extend its educational reach to industry and the general public.

AIM Academy coordinated closely with local community and state infrastructure—such as the Massachusetts Department of Housing and Economic Development and the Massachusetts Technology Collaborative—to support education and workforce development programs and tools for photonics deployment at universities (MIT, UR, RIT, SUNY Poly, Worcester Polytechnic Institute, and BU), and community college consortia (Quinsiggamond Community College, Springfield Technical Community College, and Berkshire Community College). In fall 2017, the Academy—together with the State of Massachusetts and regional community colleges—began a partnership program to establish several Labs for Education and Application Prototypes (LEAP) that will enable companies to train their workforce in new technologies associated with integrated photonics. The MIT LEAP site will focus on manufacturing practice, technician training, and certification, primarily in packaging and test. The Academy will be working with the other LEAP sites to create a coordinated set of capabilities that will support the region's growing industry.

AIM Photonics' support enables the Academy to build on MPhC CTR program's success with semi-annual meetings held at MIT. AIM Photonics supports another major program at MIT—the Design for Manufacturability Methods for Photonic Systems program—which is in its third year lead by Professor Duane Boning. The program objective is to develop photonic systems methods that will evaluate and help improve process variability understanding—using new processes that will fabricate device components associated with the AIM developed process design kits (PDK). The program also looks specifically at silicon-based photonics components—such as waveguides, ring resonators, and other elements used for routing, modulating, and detecting photonic information—in an integrated circuit. The information is essential in understanding process impact on device performance, yield, and reliability. The program coordinates with the SUNY Poly PDK Component library teams and the 300-mm Si photonics multi-project wafer fabrication and E-P system design teams.

Lightweight Innovations for Tomorrow

The Materials Systems Laboratory (MSL), directed by Professor Joel Clark, continues to be a key participant in the Lightweight Innovations for Tomorrow (LIFT) Manufacturing Innovation Institute. LIFT provides a national focus on expanding US competitiveness and innovation by facilitating the transition of advanced lightweight and modern metals manufacturing capabilities and of new technologies to the industrial base. Federal support is provided through the Office of Naval Research. Principle research scientist Dr. Randolph Kirchain is leading the MIT component of the LIFT activity, which focuses on cost, value, and life cycle analyses, as well as implementation strategies for both primary and secondary weight savings for automobiles. MSL faculty and staff published an extended commentary on environmental lifecycle analysis in *Natural Materials* this past year.

Reducing Embodied Energy and Decreasing Emissions Institute

Reducing EMbodied-Energy And Decreasing Emissions (REMADE) Institute is one of the latest program awards of the Manufacturing Innovation Institutes initiative supported by the US government. The award for the REMADE proposal was announced in January 2017. REMADE is led out of the Sustainable Manufacturing Innovation Alliance based at RIT. It will leverage federal funding of $70 million over five years and is matched to an additional $70 million in private cost share from industry and others organization

members, totaling over 85 participants in a tiered consortium membership model. The institute will focus on driving down the costs of technologies essential to reuse, recycle, and remanufacture materials such as metals, fibers, polymers, and electronic waste with the objective of achieving 50% improvements in overall energy efficiency by 2027. The REMADE Institute has organized its activities around five nodes: Design for Reuse and Disassembly; Manufacturing Materials Optimization; Remanufacturing and End-of-life Reuse; Recycling and Recovery; and Systems Analysis and Integration.

The MRL is supporting Professor Olivetti as the lead PI for MIT with REMADE and is coordinating MIT faculty proposals and administration of specific program award activities. Professor Olivetti is actively working with the REMADE organization and with other professors at MIT, collaborators at other institutions and with industry to respond to calls for proposals. MIT's research activities related to sustainability include materials optimization for manufacturing, as well as systems analysis and recycling with particular emphasis on metals, chemicals and polymers, fibers, and electronic wastes.

Manufacturing USA Institutes

MRL has significantly increased its support of MIT faculty engagement with the Manufacturing USA institutes. In addition to support for LIFT and AIM Photonics, MRL is supporting faculty engagement with the newly established Advanced Functional Fabrics of America (AFFOA) and REMADE. These institutes provide challenging new avenues of government-industry-academia interactions with industry for technology transfer combined with education and workforce development programs.

Advanced Functional Fabrics of America

MIT was the lead institution for a successful proposal to create the AFFOA Manufacturing Innovation Institute, which was launched in April 2016. The AFFOA program functions through a partnership with the Department of Defense (DOD), 32 universities, 16 industry members, 72 manufacturing entities, and 26 startup incubators, across 27 states and Puerto Rico. AFFOA's mission is to enable the transformation of traditional fibers, yarns, and textiles into highly sophisticated integrated and networked devices and systems.

The AFFOA headquarters and research facility was opened in Cambridge, MA on June 19, 2017. The facility includes a Fabric Discovery Center that provides end-to-end prototyping from fiber design to system integration of new textile-based products, and will be used for education and workforce development. It also includes a startup incubation space for companies spun out from MIT and other partners who are innovating advanced fabrics and fibers for applications ranging from apparel and consumer electronics to automotive and medical devices.

The MIT membership with the AFFOA program is led by ChemE professor Gregory Rutledge and is administered through the MRL. In May 2018 Assistant Professor Skylar Tibbits from the MIT School of Architecture + Planning received the first award from AFFOA for his proposal—MIT Shape-Shifting Climate-Adaptive Garment. The project award will include collaboration with Associate Professor A. John Hart from the Department of Mechanical Engineering (MechE), Iowa State University, and two

companies (Ministry of Supply based in Boston, and Hills Inc. based in Florida). Partnering with AFFOA and the Fashion Institute of Technology (FIT), the Institute held a joint FIT/MIT/AFFOA Summer Workshop that took place over a two-week period in June and involved six students. Students spent one week at MIT in Cambridge and one week at FIT in New York City to explore and develop clothing concepts using advanced functional materials that incorporate 3D printing or advanced knitting technologies.

Kim Vandiver—MechE professor and director of the Edgerton Center—received a subaward from Greater Lawrence Regional Vocational Technical School, supported by AFFOA, for the creation of a new Advanced Functional Fabrics (AFF) Career Pathway curricula program. The program elements include how AFFs are made, including fiber design, textile design, and product design. The objective of the curriculum is to support the development of the next generation of multi-skilled manufacturers by exposing students to the technical skills associated with manufacturing of advanced functional fabrics.

Singapore-MIT Aliance for Research and Technology Low Energy Electronic Systems

The Singapore-MIT Alliance for Research and Technology (SMART) Low Energy Electronic Systems (LEES) Interdisciplinary Research Group is directed by Professor Fitzgerald and managed through the MRL. It is in its second year of a five-year Phase II program and has a budgeted research volume of approximately $1.3M per year for the first four years, and a ramp-down budget of $650K for the fifth and final year. The Singapore-based volume is approximately three times greater.

The SMART program involves seven MIT faculty and an MIT senior research scientist, as well as their students and postdocs based at MIT. Eleven faculty from Nanyang Technological University (NTU) and National University of Singapore (NUS) are also involved in collaborative research. Twenty-four MIT staff and postdocs are now supported in Singapore for research based there.

The goal of the LEES program is to demonstrate practical approaches to integration of compound semiconductor devices with conventional Si-based integrated circuits. Compound semiconductor devices have superior properties for use in photonic and power devices compared to silicon. These devices include solid state lasers, light emitting diodes, and high-power high electron mobility transistors. Mature silicon integrated circuit technology provides capabilities for high-performance computation and data analysis. Integration of compound semiconductor devices with silicon circuits will enable technologies for:

- High-speed communication within and between circuits
- Advanced displays and lighting made smart through integration with silicon-based control circuits
- Improved wireless communication technologies
- On-chip power management for low-power circuits to be used in mobile technologies

The LEES program has created an environment that encourages experts in materials processing, device and circuit design, and systems architecture to work in close concert to develop fundamentally new integrated circuit technologies that will enable new applications. To implement these new technologies, LEES developed a 200mm wafer processing facility in Singapore that includes two state-of-the-art metal organic chemical vapor deposition systems, as well as other facilities that include capabilities for conventional chemical vapor deposition, wafer bonding, chemical mechanical polishing, and materials and device characterization. Coupled with other facilities available through collaborations with NTU and NUS, full capabilities for III-V device processing on silicon substrates has been developed. Collaborations with two semiconductor integrated circuit foundries have also been established and wafers can pass from these foundries to the LEES facility and then back into the foundries for different stages of circuit processing. Through these collaborations, LEES compound semiconductor devices have been integrated with Si integrated circuits to provide new functionalities using the existing integrated circuit (IC) manufacturing infrastructure. This will enable rapid adoption of processing and design methodologies developed in LEES in the electronics industry.

Center for Electrochemical Energy Storage

The Center for Electrochemical Energy Storage (CEES) continued into its fifth year in 2018 and will ramp down in 2019. CEES is one of approximately ten Centers for Research Education and Innovation (CREIs) that provide the primary support for research and teaching at the Skolkovo Institute of Science and Technology (Skoltech), which was founded through the MIT-Skoltech Initiative in 2011. Each of the original set of CREIs was based on collaborations. In the case of CEES, it was Skoltech, Moscow State University, and MIT. CEES is the only remaining center in which MIT plays a lead role.

The CEES team is highly interdisciplinary in nature and involves faculty from MIT MechE, ChemE, DMSE, and Chemistry, as well as faculty from the Departments of Physics and Chemistry at MSU, and five faculty at Skoltech, including the center director.

Research in CEES is focused in three areas, also known as thrusts, chosen to target technologies that will replace current Li-ion battery technology; specifically, thrust 1—advanced metal-ion batteries, thrust 2—rechargeable metal-air batteries, and thrust 3—fuel and electrolysis cells.

In the past year, research in thrust 1 included development of battery materials needed to replace Li with earth-abundant Na; new metaphosphate compounds and semi-solid carbon electrode-based electrolyzers for redox flow batteries; and materials for thin film batteries for integration with microelectronic autonomous sensor systems. Research in thrust 2 included extensive modeling and experimental studies focused on development of quantitative descriptors of materials that catalyze surface redox processes and optimize efficiency of metal air batteries and ions that will serve as redox mediators in electrolytes. Research in thrust 3 included modeling and experimental research on mixed ionic and electronic conductors for improved efficiency and low temperature operation of solid oxide fuel cells (SOF cells), and extensive modeling studies of improved catalysis of surface redox reactions for high-efficiency SOF cells. The latter included density functional theory analyses of over 600 materials with perovskite structures to obtain descriptors for optimized catalytic activity.

CEES research in 2017 and so far in 2018 has led to 30 journal publications, including two each in *Science*, *Nature Chemistry,* and *Nature Materials*. CEES research has also been the focus of many invited and keynote presentations at conferences. CEES researcher Professor Yang Shao-Horn was elected to the National Academy of Engineering (NAE), joining CEES researchers Christopher Cummins who was elected to the National Academy of Science last year and NAE member Yet-Ming Chiang. Discoveries made by Chiang involving semi-solid carbon electrode-based electrolyzers for flow-based batteries will be featured in a workshop sponsored by Breakthrough Energy Ventures and in a course to be offered this fall titled "Energy Ventures".

Industry Interactions

MRL supports faculty research efforts with industry collaboration over a wide range of materials and science-based applications from metallurgical coatings for strength and corrosion resistance to integrated photonics, solar cells, and batteries. MRL supports many ongoing research programs with faculty, including: Professor Christopher Schuh's research with Mitsubishi Materials and ORMCO; Professor Kimerling's programs with 3M, Global Foundries, NTT Electronics, iNEMI, and AIM Photonics; Professor Allanore's programs with Tavarua and Sumitomo Metal Mining; Dr. Kirchain's research with Lenovo and Rio Tinto; Professor Olivetti's program with Advanced Micro Devices; Professor Cem Tasan's research with Metalsa; and Senior Research Scientist Jurgen Michel's programs with Futurewei and Advanced Research Projects Agency-Energy (ARPA-E). MRL will facilitate interactions between the Institute, MIT faculty, and the companies. MRL also provides program management support as needed and will seek to engage the individual companies for future development of research.

The MRL also supports faculty with the establishment and operation of consortium research programs with industry. Two ongoing programs for 2017 and 2018 are MSL (Professor Clark and Dr. Kirchain) and MPhC (Professor Kimerling).

MRL partners with Industry Liaison Program (ILP) officers in support of company inquiry and members' interests in faculty research. MRL support not only includes coordination with ILP officers and faculty for meetings but also provides technical briefings and seminars by the MRL director and associate director. Significant company meetings coordinated with ILP officers throughout the year were provided to senior executives and researchers from Braeca Minsur, NGK, Sinopec, Tosoh, and Yamaha. MRL also supports other major ILP sponsored events including its R&D conferences in Japan and at MIT.

In Fall 2017, MRL and ILP included a Frontiers in Materials Research session for the ILP Research and Development Conference. Speakers participating in the conference included Professor Carl V. Thompson, Professor Allanore, Professor Jennifer Rupp, Professor Polina Anikeeva, and Dr. Jurgen Michel. Topics covered by the speakers included: high temperature material extraction and processing; engineering ceramic and glass materials for energy storage; sensing and computing; germanium for high performance solar cells and photonic devices; and flexible stretchable nanowire coated fibers for optoelectronic probing of spinal cords.

Industry Collegium

MRL Industry Collegium consists of four companies that provide direct financial support for discretionary activities through annual donations. Representatives from these companies work with MRL throughout the year to identify opportunities for collaboration and participate in MRL's annual Materials Day Symposium and Poster Session. Current collegium members include Applied Materials, Ishikawajima-Harimi Heavy Industries, Merck KGaA, and Raytheon.

New Programs with Industry

New industry-supported research programs with MRL that were initiated by faculty in FY2018 include: Dr. Anu Agarwal's research with Radiation Monitoring Devices; Professor Allanore's research with Advanced Potash Technologies; Professor Kimerling's research with Microsoft; Dr. Kirchain's research with International Seabed Authority and Ford Motor Company; Professor Tasan's research with Proctor and Gamble, SNCF, and Yamaha. Topics covered by the new research programs include investigation of chalcogenide glasses for optical based communication and sensing; germanium films for integrated electro-optical devices; economic analyses of materials processing operations; and the processing and characterization of metals and metal alloys.

Shared Experimental Facilities

Shared Experimental Facilities (SEFs) are a critically important resource to both the MRSEC program and to the MIT community, as well as to a number of outside academic and industrial organizations. Currently there are four major facilities: Materials Analysis, Electron Microscopy, X-ray Diffraction, and Nano Materials. These are staffed by a team of highly motivated professionals. During the year, more than 1,090 different individuals—representing 18 MIT departments, labs, and centers, 13 outside academic units, and 12 outside commercial units—utilized these facilities.

Beyond the special role the SEFs play in the training and education of MIT students, they are also an important part of the MRSEC education programs. Undergraduates participating in the summer internship programs (Research Experiences for Undergraduates and Community College Students) are trained to use equipment in the SEFs to conduct their research. Teachers in the Materials Research Experience for Teachers program spend one morning each week learning about the capabilities and research applications of the equipment in the SEFs. Some of them are also trained to use the instruments for their research projects. Also, seven technical courses were offered by the SEF technical staff to the MIT community as part of the Independent Activities Period of January 2018. Finally, the SEFs are included in visits to the MRSEC by various groups of middle and high school students.

During FY2018, a new MRSEC in situ scanning electron microscopy characterization facility (ISCF) was formed as part of the Electron Microscopy (EM) SEF. With funding from the Tasan group, the Lord Foundation, MRSEC discretionary funds, DMSE, the Office of the Vice President for Research, and the School of Engineering, a new SEM in situ analysis testing user facility was put into place. When the ISCF is fully functional, the facility will be able to carry out in situ SEM uniaxial tension, compression, bending, nanoindentation, and electrical property characterization tests, as well as additional novel in situ SEM experiments.

MRSEC continues to be an active participant in the NSF Materials Research Facilities Network (MRFN). Participation in this network enables access to MRL facilities by researchers from other universities, particularly those with limited research tools and minority-serving institutions. A process has been established that involves the submission of a short proposal outlining the analysis to be done and how the results will impact the proposer's research program, and, if relevant, educational activities. During this period Kaila Holloway—from Howard University and a 2017 MRSEC REU student—used MRFN funds in the EM SEF to complete research for a project at Howard University independent of her REU duties. A member of professor Ellie Fini's research team from North Carolina Agricultrual and Technical State University used the EM SEF to complete the research started in prior years.

Interactions with MIT.nano

Since its formation, MRL has worked closely with MIT.nano to coordinate and plan collaborative activities including the utilization of research areas based on equipment performance requirements. MRL is represented on the MIT.nano leadership team by Professor Thompson and on the Tool Committee Subgroup on Metrology by Professor Geoffrey Beach. Vladimir Bulović, MIT.nano director, serves on the MRL Internal Advisory Board. Professors Bulović, Thompson, and Beach have ongoing discussions focused on the identification of other modes and mechanisms of collaborations that support the missions of both organizations.

MIT.nano offers unique capabilities in terms of electromagnetic and vibration isolation, providing enhanced performance to materials characterization systems. It is likely that some of MRL/MRSEC SEFs will be relocated to MIT.nano. The technical staff responsible for the facilities in MIT.nano will report to the MIT.nano management structure. MRL will be consulted in regard to related staff hiring and evaluation of fiscal management conforming to NSF MRSEC program requirements. The SEFs operating within Building 13 will continue to be managed by the MRL, which anticipates that the facilities in Buildings 12 and 13 will be managed and billed in such a way that their different management structures will not be apparent to internal or external users.

Over time, the role of the MRL toolset will evolve to focus more on capabilities that enable materials experimentation, such as in situ and real-time imaging and analysis of evolving structural and chemical properties of materials. This strategy will complement MIT.nano's focus on materials characterization capability through Metrology.nano.

Outreach

The MRL does not limit its educational outreach to the MIT community. MRL has worked hard to establish a wide-reaching and diverse portfolio of educational outreach programs that are both innovative in nature and responsive to the needs of educators and students. MRSEC has put in place a broad range of well-received programs that impact high school students and teachers as well as undergraduate and graduate students. These outreach programs are managed by a full-time education officer who works closely with a faculty education program leader, the center director, the associate and assistant directors as well as other MRL staff.

Besides involvement in the MRSEC's formal education activities, MRSEC-supported faculty, research scientists, and graduate students participate in outreach activities with local schools, religious communities, and professional organizations.

Materials Research Experience for Teachers

For the past 19 years, MRSEC has operated a successful Research Experiences for Teachers (RET) program. This program brings high school and middle school teachers to MIT to participate in MRSEC research. The teachers spend seven weeks immersed in research during the first year of the program and then are invited to return the following summer for a flexible period of time devoted to the development of materials that will transfer their research experience to their classroom teaching. The major components of the program are research, development of classroom materials, weekly discussion meetings, and SEF tours. An important goal of the program is to document the materials developed by the teachers so that they can be shared with other educators. Lesson plans written by the teachers are distributed to other science teachers and used in teacher workshops. Five teachers participated in the 2017 summer program.

Community College Program

For the past 13 years, MRL MRSEC has collaborated with Roxbury Community College (RCC), a minority-rich two-year college in Boston, to make research experiences available to its students. The objective of this dedicated Research Experiences for Undergraduates (REU) program is to engage community college students in current materials research and encourage them to pursue careers in science and engineering. In 2007, the program was expanded to include students from Bunker Hill Community College, as well as RCC. Both colleges have significant enrollments of minority students. During summer 2017, four students—of which three are women and two are underrepresented minorities—participated in this program.

Partnership with Universidad Metropolitana

In 2008, MRL formed a collaboration with Dr. Juan Arratia at Universidad Metropolitana (UMET) to enhance the research experience of students at the three Puerto Rican universities affiliated with the Ana G. Mendez University System (UMET, Universidad del Turabo, and Universidad del Este). Dr. Arratia refers students to the REU summer internship program. At least two intern positions a year are set aside for these students. The partnership is to recruit and retain Puerto Rican science, technology, and engineering graduates. Since the inception of the program, 19 students have participated in the intern program and an additional two students spent two weeks at MIT working with graduate students to learn how to use research instruments in the SEFs. Of the 19 students who have been through the program: six are still completing their undergraduate studies; five have proceeded to graduate school (one of whom has completed her PhD); and five completed their bachelor degrees and are employed (three as engineers, one in manufacturing, and one as a systems analyst). The career status of the remaining students is unknown. In addition to their research at MIT, undergraduates who participate in the REU program contribute to the UMET's outreach to high school students in the San Juan area.

Science Teacher Enrichment Program

MRL MRSEC offered its Science Teacher Enrichment Program (STEP) for the 17th time in summer 2017. STEP, subtitled "Dustbusting by Design," is a one-week workshop focused on increasing middle and high school teachers' content knowledge, as well as providing them with experience in engineering design. The workshop correlates to Massachusetts science learning standards. Participants spend the first four days in a campus machine shop learning about the design challenges associated with the motor in a hand-held vacuum, they then immerse themselves in the engineering design process as they construct motors of their own design. The final half-day consists of a seminar on teaching the design process in K-12 classrooms. The lab portion of the program is simultaneously taught to 40 high school girls in the Women's Technology Program (WTP). Participants in STEP receive a small stipend and professional development hours. They are recruited from local school districts, from RET program former applicants, and from other MIT-based educator programs. Five teachers participated in the 2017 STEP.

A companion effort to STEP is MRSEC's collaboration with the Women's Technology Program in Electrical Engineering and Computer Science (WTP-EECS)—a four-week summer residential program for 40 high school girls from across the country, during which the participants take classes in math, computer science, and engineering. The program is designed to address a gender imbalance in the field of engineering by increasing interest and confidence in the pursuit of engineering careers. The MRSEC invites WTP-EECS participants to join the lab portion of STEP to gain hands-on engineering experience. WTP-EECS alumni report that this motor-building lab is an exciting part of the program. MRSEC continued to support WTP-EECS by providing the curriculum and supplies for this part of their program.

Science and Engineering Program for Middle School Students

MRSEC has operated a science and engineering program for seventh- and eighth-grade students from two Cambridge Public Schools for the past 26 summers. The program objectives are: introduce students to the field of materials science and engineering, demonstrate that science and engineering can be fun, and provide students with an opportunity to experience a college environment. The program consists of a week of hands-on and inquiry-based science and engineering classes for students from each school. During summer 2017, 15 seventh- and eighth-grade students attended with their science teachers, of which four were girls and seven were members of underrepresented minority groups. The students participated in hands-on activities presented by faculty, staff, graduate students, and undergraduates. The 2017 program included classes on UV light, simple DC motors, electric circuitry, polymers, glass blowing, metal casting, and solar cells.

Center Diversity

MRSEC's diversity plan consists of three integrated strategies designed to increase participation by women and traditionally underrepresented groups in its research and education programs, namely: to increase participant diversity in the MRSEC's existing programs, to develop and refine dedicated programs that target underrepresented groups, and to collaborate with other offices and departments at MIT and beyond to enhance diversity on campus and in science and engineering fields.

MRSEC Participants, June 1, 2017-April 30, 2018

Program	Female	Minority	Total participants
Middle School Program	4	7	15
Women's Technology Program	40	11	40
Research Experience for Teachers	2	0	5
Science Teacher Enrichment Program	3	0	5
Summer Internship Program (Research Experience for Undergraduates [REU])*	7	3	14
Community College Program (REU)	3	2	4
Undergraduate Research Opportunities Program**	6	3	9
Graduate Students**	6	0	37
Postdoctoral Associates**	4	2	17
Faculty	8	2	27
Totals	**83**	**30**	**173**

*These numbers include two students paid with non-MRSEC funds.

**Numbers for these participant groups include individuals paid directly by the grant, as well as those who worked on MRSEC research for academic credit or were supported with other funds.

Summer Research Internship Program

For 34 years, MRL MRSEC has sponsored a summer internship program for promising undergraduate researchers from other colleges and universities nationwide. MRL summer internship is a National Science Foundation REU for undergraduate students. The program brings the best science and engineering students in the country to MIT for graduate-level materials research in laboratories of participating faculty. The program culminates in a poster session held in the lobby of Building 13, where students present their research to the MIT community.

The 2018 eight-week program ran from June 17 to August 11 and involved 14 faculty and 12 students from schools that included the University of Utah, Oregon State University, University of Rhode Island, Brown University, the University of Illinois at Urbana at Champaign, Johns Hopkins University, University of Puerto Rico at Mayaguez, Howard University, Oregon State University, and the University of Florida.

2017 summer scholars and community college teachers

Materials Day

Sharing knowledge and insight with others in the materials science and engineering field can lead to new ideas, collaborations, and breakthroughs. Once a year, the materials community is invited to Materials Day, a celebration to recognize and honor the many important accomplishments and achievements of the past year and to talk about the future.

Held in the fall, Materials Day is a daylong symposium on a featured topic related to materials science and processing, followed by a graduate student/postdoctoral associate poster session. The Materials Day 2017 Symposium focused on frontiers in materials research. Seven presentations were made over the course of the day, from both faculty and industry professionals, and the event drew a record crowd of more than 235 attendees.

Invited speakers and their talk titles included: Sandia National Laboratories' Dr. Julia Phillips, "Materials Research: From Vision to Reality;" MIT Professors John Hart, "Additive Manufacturing Across Length Scales;" Jennifer Rupp, "Engineering Ceramic and Glass-Materials for Energy Storage, Sensing and Computing;" Pablo Jarillo-Herrero "Quantum Transport and Optoelectronics with van der Waals Heterostructures;" Antoine Allanore, "Harnessing High Temperature Materials for Extraction and Processing;" Polina Anikeeva, "Electronic, Optical and Magnetic Materials for Probing and Interrogation of Neural Function;" Juejun Hu, "Optical Phase Change Materials: The Altering Face of a Chameleon;" and MRL Director Carl V. Thompson led the opening welcome presentation.

The poster session that followed panel presentations and discussions included over 73 posters presented by graduate students and postdoctoral associates from Departments of Chemical Engineering; Chemistry, Civil and Environmental Engineering; Electrical Engineering and Computer Science; Aeronautics and Astronautics; Materials Science and Engineering; Mechanical Engineering; Nuclear Science and Engineering, Biological Engineering; and Physics. The posters were judged by a panel of representatives from industry, as well as by members from the MRL advisory board. Winners received award certificates and $500 prizes. Poster session winners were:

Dena Shahriari
Poster Title: Thermally drawn porous scaffolds and optoelectronic fiber-based probes for intervention in the nerve tissue
Faculty Advisor: Professor Polina Anikeeva
Department of Materials Science and Engineering

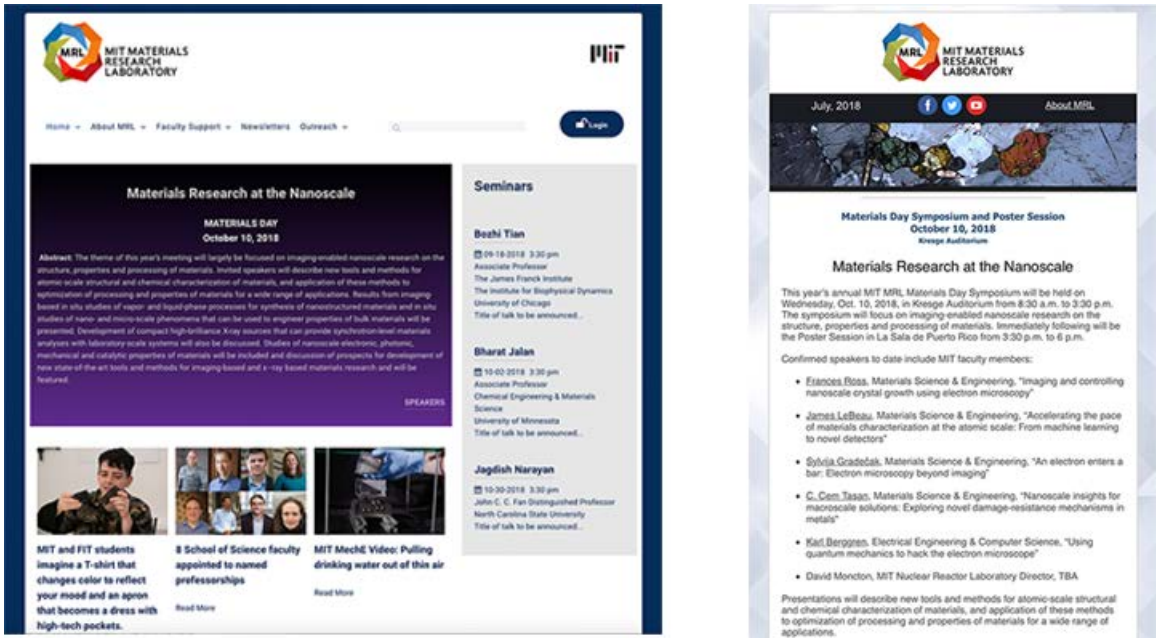
Vera Schroeder
Poster Title: Bio-inspired carbon monoxide sensors with voltage-activated sensitivity
Faculty Advisor: Professor Timothy Swager
Department of Chemistry

Sebastian Pattinson
Poster Title: Printed mesh materials with locally tailored elasticity for compliant wearable and implantable devices
Faculty Advisor: Professor A. John Hart
Department of Mechanical Engineering

Materials Day 2017 Poster Session winners, from left to right Dena Shahriari (Research Laboratory of Electronics); Vera Schroeder (School of Science); Robert Pattinson (Department of Mechanical Engineering)

Materials Day 2018 is scheduled for October 10, 2018 and the workshop will focus on materials research at the nanoscale.

Communications



The MRL website homepage featuring a news and announcements segment, which can be sorted by topic, and the MRL e-newsletter, which is sent out monthly.

The MRL website went live in October 2017 along with the launch of the new Materials Research Laboratory. The website is a campus-wide materials reporting resource and has become a hub where information is shared not only with other materials researchers at MIT but also with the world. Updated daily, the website highlights the latest news stories being generated for the MRL e-newsletter, as well as related news from the MIT News Office. The newsletter features faculty members and the new research activities on which graduate students and post-docs are working. This year, 40 original articles were written and photographed for the e-newsletter; of those, 14 articles were picked up by the MIT News Office for use on the MIT website. Five other departments within MIT picked up MRL articles, and 12 organizations outside of MIT also picked up MRL news. MRL

also produced 12 videos and it continues to use social media (Twitter and Facebook) to communicate and expand its audience. As a result, MRL has grown its following.

This year was of particular importance because MRL rebranded itself with a new logo, viewbook, brochures, and all new marketing collateral. The launch was done in close proximity to the capstone event for MRL—Materials Day.

This year MRL also implemented a completely automated registration process for summer scholar applicants. Starting with a broader outreach effort to over 970 colleges and universities from across the United States, MRL had 284 applicants this year using the new registration system.

Promotions and Selected Honors and Awards

MRL faculty received numerous awards and honors, as individually reported in the reports of their home academic departments. Especially noteworthy individual are:

Assistant Professor Jennifer Rupp of DMSE won the Merck KGaA Displaying Futures Award on June 12, 2018. Rupp's team was one of three winning teams that will receive access to the company's global network, mentoring, and resources and up to $50,000 each to help shape their ideas. The on-chip all-solid-state glucose micro fuel cell for energy harvesting in the human body invention will enable the conversion of glucose in the bloodstream of the human body into electricity with the first ever all-solid-state miniature glucose fuel cell. This technology may offer revolutionary possibilities for applications such as pacemakers, implantable sensors and other implantable devices that require a constant source of electricity.

Professor Yang Shao-Horn of MechE was one of four MIT faculty elected to the National Academy of Engineering this year. She was cited for contributions to design principles for catalytic activity for oxygen electrocatalysis for electrochemical energy storage for clean energy. Professor Shao-Horn also won the Faraday Medal on April 19, 2018. The medal, awarded annually by the Electrochemistry Group of the Royal Society of Chemistry to an electrochemist working outside the UK and Ireland in recognition of their outstanding original contributions and innovation as a mid-career researcher in any field of electrochemistry. Professor Shao-Horn is the first female winner of this prestigious medal. She won for her research into exploiting chemical/materials physics and physical/materials chemistry principles at interface and in bulk to design materials/processes and control the kinetics of (electro)chemical reactions. These materials/processes include lithium ion storage and the making of sustainable fuels such as water splitting and CO_2 reduction, critical for the deployment of clean energy technologies.

Professor Bilge Yildiz of the Department of Nuclear Science and Engineering was awarded one of nine seed grants from the MIT Energy Initiative in spring 2018 for her work on Oxidative coupling of methane using ion-conducting ceramic membranes. Professor Yildiz received a $150,000 grant to explore her energy research projects. Professor Yildiz also won the Ross Coffin Purdy Award on June 22, 2018. The Purdy award is given to an author, or authors, who made the most valuable contribution to ceramic technical literature published two years prior to the selection year. Professor

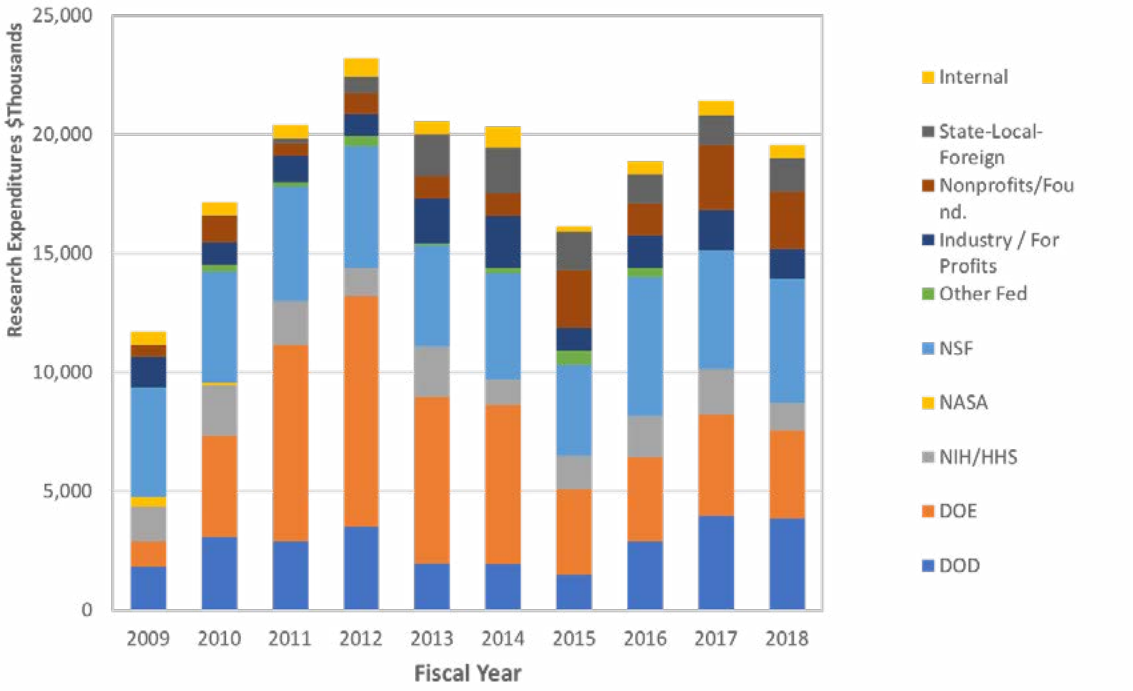
Yildiz was awarded for her paper, "Improved chemical and electrochemical stability of pervskite oxides with less reducible cations at the surface," published in *Nature Materials*, (vol. 15, pp.1010-1016, 2016).

Research Volume

Total expenditures under MRL totaled $22.3 million in FY2018. Research expenditures from sponsored programs totaled $19.6 million, a decrease of 8.8% over FY2017 (figure 6). Major program expenditures included the work of: Professor Fitzgerald and eight co-PI's on the Low Energy Electronic Systems Program within SMART; Professor Thompson and five co-PI's on the Skoltech Center for Electrochemical Energy Storage; Professor Harry Tuller and five co-PI's on the program on "Chemomechanics of Far-from-equilibrium Interfaces" supported by the DOE; Professor Ashoori and seven co-PI's on the Center for Integrated Quantum Materials with Harvard University and supported by the National Science Foundation; and Professor Kimerling and six co-PI's on the American Institute for Manufacturing Integrated Photonics with the Research Foundation for the State University of New York and supported by the DOD. Other significant faculty research groups are led by Professor Pablo Jarillo-Herrero, Assistant Professor Ibrahim Cisse, Associate Professor Jeffrey Gore, Associate Professor Nuh Gedik, Senior Research Associate Jurgen Michel, Associate Professor J.J. Hu, and Assistant Professor Allanore.

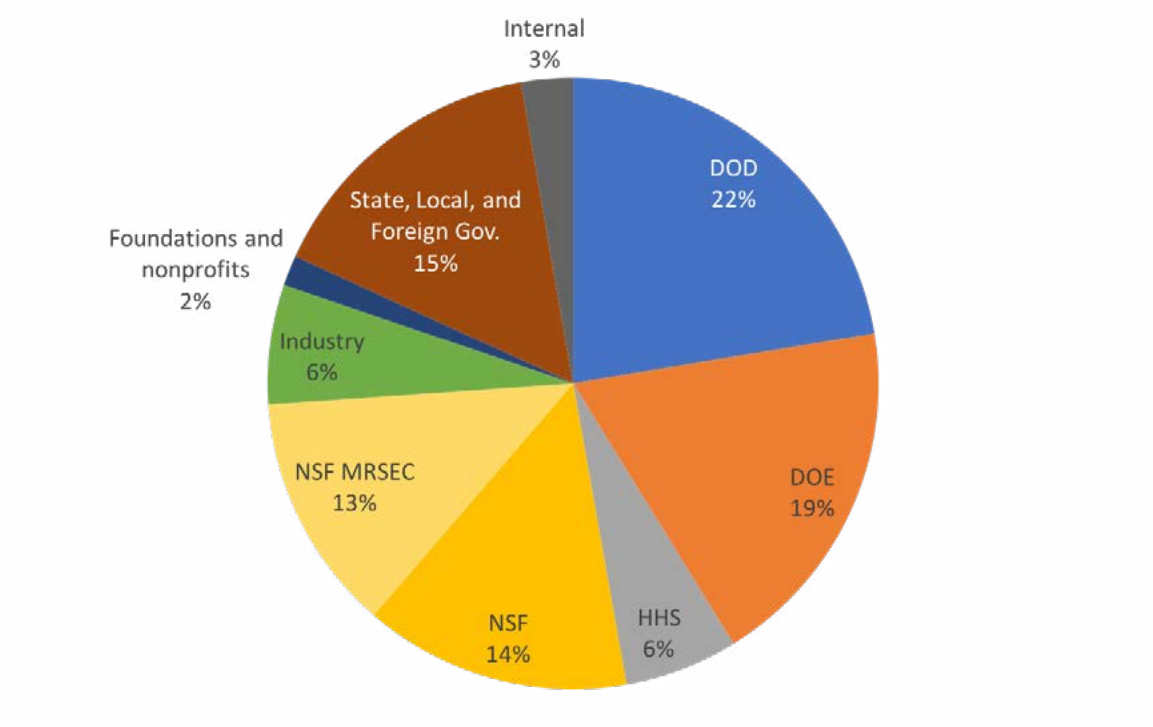
MRL researchers are not only sponsored by a variety of companies but also supported by nearly every major federal research sponsoring agency, including the NSF, DOE, National Institutes of Health, and multiple DOD agencies.

MRL Research Expenditures by Sponsor, FY2009–FY2018



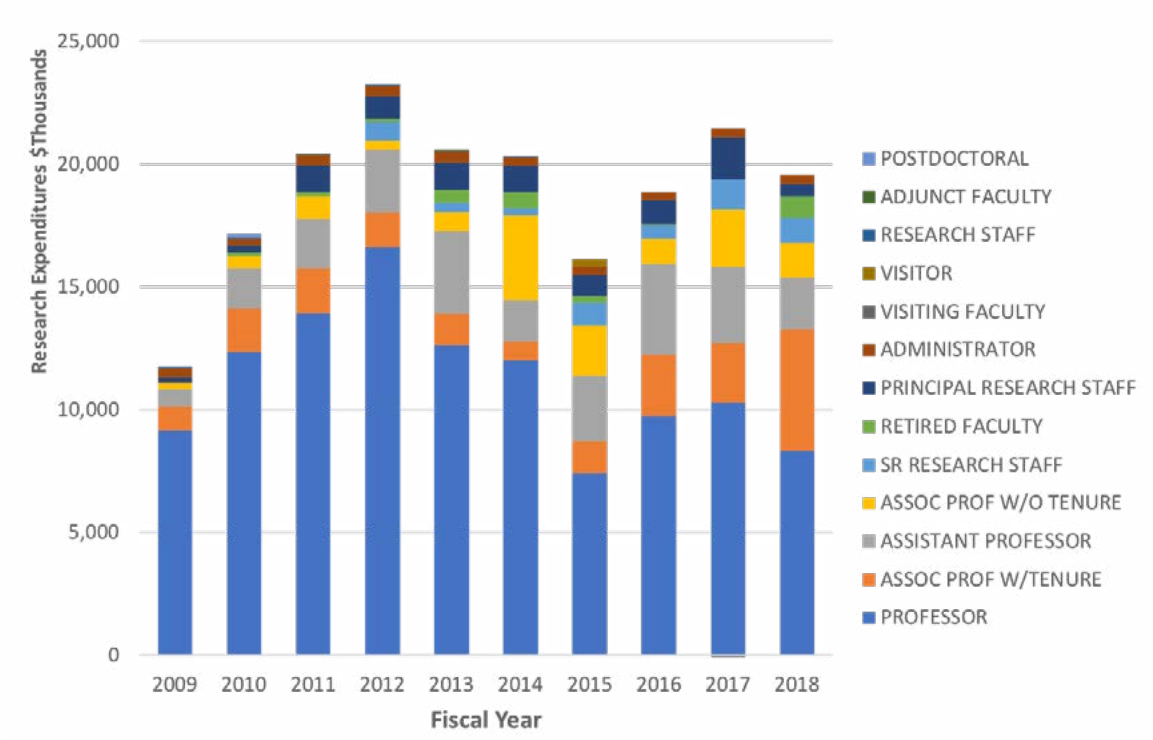
MRL sponsored research expeditures FY2009-FY2018, includes historical research expenditures for the NSF MRSEC program, formerly administered by CMSE

MRL Research Volume by Major Sponsors, FY2018



MRL research volume by major sponsors FY2018 ($19,573,667).

MRL Research Expenditures by Principal Investigator, FY2018



MRL research expenditures by principal investigator FY2018

Overview and Outlook

The merger of MPC and CMSE to form MRL became official in October of 2017. MRL is responsible for management of Building 13 and the former MPC and CMSE staffs are now co-located in the building. Staff activities have been merged within a reorganized reporting structure. MRL senior leadership consists of Professor Thompson, director; Professor Beach, co-director; Mark Beals, associate director, with responsibilities in program management and industrial outreach; Gilbert Cordova, assistant director for finance; and Susan Dalton, assistant director for the MRSEC program and MRL operations. After a critical and successful review of the MRSEC program in the spring, MPC and CMSE names and logos were retired and signage with the new MRL logo was installed throughout Building 13. New internal and external advisory boards were formed and met with the MRL leadership to help define MRL's mission, to set its goals, and to identify mechanisms to achieve those goals. The transformation to a new unified laboratory is now complete.

MRL supports interdisciplinary materials research in a number of ways. Direct funding of interdepartmental research groups and seed grants for junior faculty is provided by the NSF MRSEC program as well as by other large programs such as the NSF Center for Quantum Materials. MRL also assists faculty in developing research programs supported through a range of sources that include most federal funding agencies, domestic and international corporations, and state and international governments. Industry support is provided through grants from individual companies, consortia involving multiple companies, and through the four Manufacturing Innovation Institutes managed by MRL. MRL has also played an important role in bringing together interdisciplinary teams of faculty to compete for large programs supported by the Singapore-MIT Alliance for Research and Technology and Skoltech.

MRL outreach activities are also extensive and include programs for high school students and teachers, partnerships with community colleges and other universities, summer intern opportunities for undergraduates from other universities, workforce development for high-tech manufacturing, and partnerships and programs with industry. In the coming year, new modes of interactions with industry through a laboratory-level consortium will be developed, with the active aid of the MRL External Advisory Board. MRL also has a new website that will serve as the primary portal for internal and external communication of materials research activities at MIT. MRL's staff science writer produces original articles and videos highlighting research breakthroughs and MRL outreach activities. These are also featured in the monthly MRL newsletter, which is distributed to materials researchers nationally and globally.

Non-MRSEC research volume as measured by expenditures decreased by 9.2% in FY2018 to $17,110,538. The total volume including the MRSEC program increased by 3.9% to 19,573,667. The drop in non-MRSEC volume was associated in large part with the ending of several large programs supported by non-domestic corporations. The delay of renewal processes and proposal requests by federal agencies during a period of budgetary uncertainty in fall 2017 also impacted the FY2018 research volume. As always, the total volume is volatile and it is difficult to reliably project future funding levels. Among large programs, the Skoltech Center for Electrochemical Energy Storage, the LIFT

Manufacturing Innovation Institute, an ARPA-E, and a Multi-investigator DOE program will enter wind-down phases in FY2019 and the AIM photonics Manufacturing Innovation Institute program is likely to have a budget reduction in FY2019. At the same time, several new DOE- and Industry-supported programs are likely to start in FY2019. MRL anticipates that the total research expenditures will hold even or see only a small decrease in FY2019.

The new MRL External Advisory Board met in October of 2017 and in its report to Vice President for Research Maria Zuber it called the formation of MRL "a watershed event in the history of materials research at MIT." It also noted that the formation of MRL "offers unprecedented opportunities for increasing the coherence, visibility, and impact of the MIT materials community far beyond the borders of the Institute and for a robust partnership of that community with MIT.nano." The Advisory Board particularly encouraged MRL leadership to utilize its and MIT's convening power to bring together partners from industry and other US and global institutions to address future challenges and opportunities for materials research. The Board supported plans of the MRL directors to reinvent the MPC Collegium as a more vibrant industry consortium that would support research, as well as the other activities of the MRL. It also provided feedback on how the consortium might best be designed to ensure a mutually beneficial collaboration with industry. The Board strongly supported MRL's focus on interdisciplinary research and urged an expanded focus on transdisciplinary research and convergence. The Board members have continued to engage with MRL leadership in discussions of these opportunities on many occasions subsequent to the meeting in October. These discussions will lead to a range of new activities in the coming year, including a series of Corporate Materials Innovation Workshops that will be initiated in September.

The formation of MRL has involved many transitions, including staff reorganization, space changes, and definition of its mission. It has also created unprecedented opportunities to better serve the broad materials research community at MIT and to support engagement of that community with industry, governments, and other universities at both national and global levels. The leadership and staff look forward to building on the many opportunities that the formation of MRL has created.

Carl V. Thompson
Director
Stavros Salapatas Professor of Materials Science and Engineering