Interdisciplinary research on materials - scientific breakthroughs - transformative engineering - outreach.
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Images on pgs. 7, 9-13, 18 by: Maria E. Aglietti
Introduction to the MRL

The MIT Materials Research Laboratory (MRL) starts from a foundation laid by its merger partners, the Materials Processing Center (MPC) and the Center for Materials Science and Engineering (CMSE), based on fundamental scientific research, practical engineering applications, educational outreach, and shared experimental facilities.

The MRL will provide a unified nexus for support of interdisciplinary interactions among materials researchers within MIT. It will serve as a portal and mediator for external interactions with industry, government and other academic institutions. It will also partner with MIT.Nano and other organizations to provide the tools and research environments that promote research breakthroughs, and will build on a rich history of innovation and entrepreneurship in the MIT materials research community to help translate breakthroughs to technologies that impact society. The creation of the MRL will also better enable MIT to communicate to the public the profound role that materials research plays in creating and advancing all of the technologies that affect our daily lives.

By providing a coordinated infrastructure to support the basic research, education, outreach, and industry activities of CMSE and MPC, the new MRL will be far more than the sum of its parts. I expect that MRL will further enhance the scope and impact of such coordinated efforts at MIT.

“The merger of these two successful centers will streamline the organization of materials research on campus in a manner that will enhance the ability for effective collaboration”

Maria Zuber
MIT Vice President for Research

MRL encompasses research on 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 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.
The MRL will serve interdisciplinary groups of faculty researchers, spanning the spectrum of basic scientific discovery through engineering applications and entrepreneurship to ensure that research breakthroughs have an impact on society. The center engages with approximately 150 faculty members and scientists from across the Schools of Science and Engineering who are conducting materials science research. The newly formed MRL will work hand-in-hand with MIT.nano, the central research facility being built in the heart of the MIT campus due to open in June 2018, to enhance the toolset available for groundbreaking research. We look forward to working with them not only as an important partner, but as a good next door neighbor.

Shared experimental facilities, including X-Ray diffraction, scanning and transmission electron microscopy, probe microscopy, and surface analytical capabilities, are used by more than 1,100 individuals each year. MIT.nano, in concert with MRL, will be able to work together to look at new strategies for trying to maintain state-of-the-art equipment, to find funding sources and to figure out ways to not only get the equipment but to have trained professionals running that equipment.

MRL will support campus-based work by MIT faculty in three Manufacturing Innovation Institutes [MIIs], with a fourth likely in the area of materials sustainability. Current initiatives include LIFT [Lightweight Innovations for Tomorrow]; AIM Photonics [American Institute for Manufacturing Integrated Photonics], and AFFOA [Advanced Functional Fibers of America] as well as oxide-based fuel cell materials and higher efficiency solar cells.

**CARL V. THOMPSON**  
Professor and Director, MRL

Professor Carl V. Thompson is the Stavros Salapatas Professor for Materials Science and Engineering and was previously the Director of MIT’s Materials Processing Center for eight years. His research focuses on processing of thin films and nanostructures for applications in microelectronic, microelectromechanical and electrochemical devices and systems.

**THE KEY TO SUCCESS**

**EXTERNAL ADVISORY BOARD**  
The MIT Materials Research Laboratory External Advisory Board is made up primarily of representatives from industry, government and also includes members from national labs and other universities.

**INTERNAL ADVISORY BOARD**  
The Internal Advisory Board is made up of 10 MIT faculty members from five departments in the School of Engineering and School of Science.

**COLLEGIUM**  
The Industry Collegium is made up of companies who wish to partner more closely with MIT researchers on innovative materials research and development projects.

“Research breakthroughs by their very nature are hard to predict, but what we can do is create an environment that leads to research breakthroughs.”

Professor Carl V. Thompson  
Director, Materials Research Laboratory
The Leadership

GEOFFREY BEACH
Associate Professor and Co-Director, MRL
Professor Geoffrey Beach is the Principle Investigator for MIT’s NSF-supported Materials Research Science and Engineering Center and is on the faculty of Department of Materials Science and Engineering. His research focuses on spin dynamics and “spin-electronics” in nanoscale magnetic materials and devices.

MARK BEALS
Associate Director, MRL
Mark Beals is the Associate Director of the MRL. He is responsible for program management of sponsored research programs. He is actively engaged in the research and development of integrated photonic devices and circuits using silicon substrates and solid-state solar thermal electric materials and devices.

GILBERT CORDOVA
Assistant Director of Finance, MRL
Gil Cordova works with principal investigators and their research groups to prepare proposals and manage sponsored research accounts. Before working at MRL, Gil was the Fiscal Officer in the MIT Department of Physics where he worked with faculty, students and staff on financial operational matters pertaining to academic, funding, and educational research accounts.

SUSAN DALTON
Assistant Director, MRSEC Program & MRL Operations
Susan Dalton is the Assistant Director of the MRL. She is responsible for the day-to-day operational management of the NSF Materials Research Science and Engineering Center (MRSEC). Her primary duties include the financial, grant and shared facilities management of the program at MIT.
Meet The Team

MARIA AGLIETTI
Senior Communications Officer

DIANNE BROOKS
SRS Financial Staff

GINA FRANZETTA
Administrative Assistant II

JACK KOSEK
Assistant Director
Center for Electrochemical Energy Storage

LARS LLORENTÉ
Environmental Health & Safety Coordinator

DENIS PAISTE
Science Writer

SUSAN ROSEVEAR
Education Officer

LISA SINCLAIR
Senior Administrative Assistant & Human Resources Administrator
ORGANIZATION OVERVIEW

RESEARCH THRUSTS

- Energy harvesting, conversion and storage
- Quantum materials and spintronics
- Metals processing
- Solid-state ionics
- Photonic devices and systems
- Materials integration for microsystems
- Complex biogels
- Functional fibers
- Materials modeling
- Soft materials
- Electronic properties of complex oxides
- Materials systems and sustainability

OUR ORGANIZATION

1. Research Enterprise
   More than 150 MIT faculty and scientists (collaborative, interdisciplinary research, individual faculty research). Annual research volume of $21.5 million.

2. Facilities
   Shared experimental facilities including X-Ray diffraction, scanning and transmission electron microscopy, probe microscopy and surface analytical capabilities, and the substrate engineering laboratory.

3. Staff
   The Materials Research Laboratory encompasses 14 administrative staff, seven experimental facilities staff and approximately 100 research appointments.
The History

Following a science-to-systems approach through research to create opportunities through technology transfer.

The Materials Processing Center (founded in 1980) brings to the partnership its wide diversity of materials research, funded by industry, foundations and government agencies, while the Center for Materials Science and Engineering brings its seed projects in basic science and Interdisciplinary Research Groups, educational outreach and shared experimental facilities, funded under the National Science Foundation Materials Research Science and Engineering Center program [NSF-MRSEC].

From its beginnings in metals processing with NASA support, MPC evolved into a multi-faceted center with diverse sponsors of research in energy harvesting, conversion and storage; fuel cells; quantum materials and spintronics; materials integration for microsystems; photonic devices and systems; materials systems and sustainability; solid-state ionicics; as well as metals processing.

Faculty, staff and students are supported by industry, foundations and government agencies to carry out fundamental engineering research on materials. The wide diversity of materials research is steeped in innovation, breakthroughs, education, and entrepreneurialism.

Seed funding through CMSE and IRG [Interdisciplinary Research Group] funding facilitated research in complex photonic crystal structures. This evolved to new directions including making photonic fibers that led to the launching of OmniGuide. That work evolved into Advanced Functional Fabrics of America [AFFOA], a public-private Manufacturing Innovation Institute devoted to creating and bringing to market revolutionary fibers and textiles.
Funded Research is Spinning Out Jobs

The CMSE and the MPC have supported research which led to new jobs through spin-out companies that include American Superconductor [superconductivity], Amberwave (strained silicon IC technology), Ambri (energy storage), Microchips (implanted drug delivery), OmniGuide Surgical [optical fiber], QD Vision [quantum dots] and Luminus Devices which specializes in solid-state lighting based on light emitting diodes [LEDs].

Groundbreaking Research

LOW ENERGY ELECTRONIC SYSTEMS (LEES)

Low Energy Electronic Systems’ goal is to demonstrate a research paradigm in which specialists in materials processing, device and circuit design, and systems architecture work in close concert to develop fundamentally new integrated circuit technologies that will enable new applications. The faculty involved are from materials, mechanical, and electrical engineering working in collaboration with faculty from the National University of Singapore and Nanyang Technological University.

AIM PHOTONICS

On July 27, 2015 the Obama administration announced the award of the Integrated Photonics Institute for Manufacturing Innovation (IP-IMI) to AIM Photonics, a public-private partnership, which will help strengthen high-tech U.S. based manufacturing. AIM Photonics brings government, industry and academia together to advance domestic capabilities in integrated photonic technology.

LIGHTWEIGHT INNOVATIONS FOR TOMORROW (LIFT)

Lightweight Innovations for Tomorrow Manufacturing Innovation Institute (LIFT) focuses on expanding US competitiveness and innovation by facilitating the transition of advanced lightweight and modern metals manufacturing capabilities and new technologies to the industrial base. It focuses on cost, value, and life cycle analyses, as well as implementation strategies for both primary and secondary weight savings for automobiles.
The Summer Scholars program, which is primarily funded through NSF’s Research Experience for Undergraduates (REU) program, brings the best science and engineering students in the country to MIT for graduate-level materials research. Each summer students spend about two months at MIT as lab interns working with professors, postdocs and graduate students on cutting edge research.

Another part of our outreach efforts include summer programs for community college students and teachers, middle and high school teachers and also the Women’s Technology Program and the K-12 Boston Area Girls’ STEM Collaborative. Teachers who participate in these MRSEC sponsored research programs often note how collaborative the research enterprise is at MIT. Several have replaced cookbook-style labs with open-ended projects that let students experience original research.

Annually the MRL hosts “Materials Day” which includes a topical symposium followed by a student poster session. Presentations are given by industry speakers and MIT faculty who represent the new generation of leaders in materials research.

"Diversity is also part of our mission, we try to broaden participation in science and engineering." — Susan Rosevear, Education Officer

Summer Scholars
The program provides undergraduates with an opportunity to immerse themselves in exciting materials research as part of a team of graduate students and postdoctoral associates under the leadership of MIT faculty.

High School Teachers
Middle and high school science teachers participate in materials research at MIT and they design classroom material based on that research. Each teacher is matched with a faculty member to carry out research in a laboratory on campus.

Community College Students
The primary goal of this program is to encourage a significant number of community college undergraduates to pursue careers in science and engineering. Current partnerships include Roxbury Community College and Bunker Hill Community College.

Women’s Technology Program
The MIT Woman’s Technology Program is a four-week summer academic and residential experience where female high school students explore engineering through hands-on classes, labs, and team-based projects.
Government and Industry Partners

COLLEGIUM

Through its Collegium the MRL develops close relationships with member companies and supports interactions with individual or small groups of faculty identified as having research interests relevant to an organization’s interests. These interactions provide opportunities to develop research partnerships that are supported through a range of mechanisms. Collegium members are also provided previews of new research activities and initiatives. Members provide important feedback on topics and approaches of greatest interest to them.

INDUSTRIAL LIAISON PROGRAM

The MRL partners with the Industrial Liaison Program (ILP) officers in support of company inquiry and members’ interests in faculty research. Support includes coordination with ILP officers and faculty for meetings, but also to provide technical briefings and seminars. Significant company meetings coordinated with ILP officers throughout the year were provided to senior executives and researchers from: 3M, Applied Materials, CBMM, Comcast, Global Foundries, Metalsa, Michelin, Microsoft, Mitsubishi Heavy Industries, NTT, NEL America, SNCF French Railways Group, Stanley Black & Decker, and Sun Edison Semiconductor. All are either members of the ILP and/or participate in the MPC Collegium or Microphotonics Center Consortium.

Professor Vladimir Bulović demonstrates how the MIT logo, patterned in thin layers of quantum dots, appears on a seemingly clear piece of glass when an LED light shines on it causing the quantum dots to glow. The thin layers of quantum dots were printed on a 3-inch square piece of glass using inkjet printing.
MRL-affiliated MIT condensed matter physicists include experimentalists Raymond C. Ashoori, Joseph G. Checkelsky, Nuh Gedik, and Pablo Jarillo-Herrero, who are exploring quantum materials for next-generation electronics, such as spintronics and valleytronics, new forms of nanoscale magnetism, and graphene-based optoelectronic devices, as well as theorists Liang Fu and Senthil Todadri, who envision new forms of random access memory, Majorana fermions for quantum computing, and unusual magnetic materials such as quantum spin liquids.

Entering its fifth year, the Center for Integrated Quantum Materials (CIQM) is a National Science Foundation Science and Technology Center (STC). The center focuses on discovering extraordinary new quantum materials to enable atomic scale electronics and photonics that transform signal processing and computation. MIT’s CIQM effort pulls together 10 Principal Investigators in the various fields of Quantum Materials by Design, Quantum Electronics and Photonics, Universal Quantum Interface, and Atomic Scale Networks.

The MRL continues to support faculty research efforts with industry collaboration over a wide range of materials science based applications from metallurgical coatings for strength and corrosion resistance to integrated photonics, solar cells, and batteries. The MPC supports many ongoing research programs with faculty including: Professor Christopher Schuh’s research with Mitsubishi Materials and ORMCO; Professor Lionel Kimerling’s programs with iNEMI and AIM Photonics, Professor Antoine Allanoir’s program with Tavarua and Sumitomo; Professor Donald Sadoway’s research with NorCo; Dr. Randy Kirchain’s research with Hangzhou Jinjiang Group and Rio Tinto; Professor Elsa Olivetti’s program with AMD; Professor Cem Taşan’s research with Metalsa and Senior research scientist Dr. Jurgen Michel’s programs with Futurewei and ARPA-E for research on microscale optimized solar-cell arrays with integrated concentration.
The shared experimental facilities (SEFs), which are housed in over 11,600 sq. ft. in the Vannevar Bush Building at MIT, have played a pivotal supportive role in many key science and engineering discoveries. They include advanced tools for both materials characterization and processing. Many of the capabilities provided by the SEFs are unique such as a TEM fitted with a cathodoluminescence system. Decisions about equipment added to the SEFs are motivated by a desire to provide and maintain large sophisticated tools not readily available to individual investigators. The SEFs not only serve the MRSEC research program, but they continue to be an important resource to the broader materials community (both inside and outside MIT). From 2006 to the present, the number of individual users per year in our facilities has steadily increased from about 500 to well over 1,000. Typical users include MRSEC supported faculty and their students, other MIT investigators and their students, researchers from other universities, and non-profit and industrial organizations. A top priority is to continually upgrade and enhance the capabilities of our SEFs.

Our SEFs are managed by a professional team of seven full-time staff members, including four PhD-level scientists with strong research backgrounds. The SEF staff in each facility, under the direction of the director and assistant director, oversee the operation of the SEFs and make recommendations on SEF policy, staffing needs, and the elimination and addition of instrumentation. Faculty user groups are utilized as needed to identify critical capital equipment needs and to provide a critical assessment of facility and staff performance. The Coral facilities lab management system is utilized for online user registration, instrument booking, safety training validation, real time instrument status monitoring, and instrument billing. SEF staff members are actively encouraged to participate in local or national meetings, publications, new technique and tool development, professional societies, or other professional growth opportunities. This ensures that they maintain state-of-the-art knowledge about new characterization tools and techniques and MRSEC relevant research developments.
Microfluidic device developed to investigate minerals/soil/fluid interaction using petrological thin sections.
Metallurgy

Associate Professor of Metallurgy Antoine Allanore aims to increase sustainability by reducing the processing costs and environmental impacts for materials. Recent breakthroughs in the Allanore Group include a new method for extracting copper from molten sulfide minerals; a high-temperature thermoelectric device to produce electricity from molten semiconducting compounds that could reuse industrial waste heat; and a new chemical process for releasing a potassium-rich fertilizer, called “hydrosyenite,” from natural feldspar rock. His laboratory also pursues the processing science of molten systems, for applications such as molten oxide electrolysis. He launched the Metals and Minerals for the Environment (MME) forum in 2015 with T. Alan Hatton, the Ralph Landau Professor of Chemical Engineering. A native of France, with several years of service in industry, Allanore joined the Department of Materials Science and Engineering in July 2012.
Eugene A. Fitzgerald, the Merton C. Flemings-SMA Professor of Materials Science and Engineering, developed along with Professor Scott Stern (MIT Sloan School) one of the two core required courses, “Venture Engineering,” for MIT’s new undergraduate minor Entrepreneurship & Innovation. He also teaches a restricted elective, “Innovation and Commercialization of Materials Technology.” He is co-author of “Inside Real Innovation – How the Right Approach Can Move Ideas from R&D to Market – And Get the Economy Moving.” He is co-founder of the Innovation Interface which is a way to promote innovation by bringing together university research expertise and corporate skills in making and marketing products. Fitzgerald is a co-founder of Amberwave Systems Corporation, 4Power LLC, New Silicon Corporation Pte. Ltd., Paradigm Research LLC, and his experience in materials and entrepreneurship has also led to participating in the founding teams of Contour Semiconductor and The Water Initiative.

Yet-Ming Chiang is Kyocera Professor in the Department of Materials Science and Engineering at MIT and one of the top battery researchers in the world. He has published over 200 scientific articles, one textbook, and holds about 60 patents. In addition to his academic research, Chiang has co-founded four companies: American Superconductor Corporation (NASDAQ: AMSC), A123 Systems, SpringLeaf Therapeutics, and 24M Technologies. Of these, three are in the area of energy technology (Am. Super., A123, and 24M) and three grew out of research in batteries (A123, SpringLeaf and 24M). 24M is working on a new type of lithium ion battery that is cheaper than what’s currently on the market. Yet-Ming Chiang founded 24M in 2010 and was a spinoff of his previous battery company A123 Systems. The idea is to create a battery that could store more energy while shrinking the other materials in the battery that he believed could be made smaller. Chiang’s latest research is in electrochemical actuators that could be used to produce large-scale “morphing” structures or materials that could enable air, water, and land vehicles to change shape in order to improve performance and energy efficiency.
A zoomed in view of an infrared lens whose thickness is only 1/10 of wavelength.
Juejun “JJ” Hu, the Merton C. Flemings Associate Professor in Materials Science & Engineering, is finding new ways to create optical and photonic systems with novel materials. His Photonic Materials Group explores light management in solar cells; photonic integration on unconventional substrates; programmable meta-optical systems; and materials and devices for infrared detection, imaging, and spectroscopy. His group’s work has led to photonic devices that are mechanically flexible and stretchable, novel ways to incorporate emerging optical materials (e.g. graphene and other 2-D materials) into integrated photonic circuits, ultra-thin meta-optics with sub-wavelength thickness which outperform traditional bulky optics, as well as new broadband transparent optical phase change materials that enable re-programmable and tunable optical systems. Hu joined the Department of Materials Science and Engineering as assistant professor in January 2015, and he was promoted to Associate Professor in February 2016.
SOFC Membranes
Strain-transport properties of micro energy converters for portable electronics.
Jennifer L. M. Rupp leads the Electrochemical Materials Laboratory at MIT, with research projects on solid-state lithium ion batteries, solid-state gas sensors, solar-powered break up of water and carbon dioxide molecules, and new memory and computing devices based on changes in electrical resistance of oxide materials. Rupp won a U.S. Patent in August 2017 for strained multilayer resistive-switching memory elements. One intriguing possibility from this work is devices that can cycle between three different states rather than the on/off states of transistors. From a materials perspective, she enjoys discovering the mass and charge transport properties of ceramic and glass type structures and establishing new device operation principles. A native of France and Germany, Rupp joined the MIT Department of Materials Science and Engineering as the Thomas Lord Assistant Professor of Electrochemical Materials in January 2017. She previously was an assistant professor of Electrochemical Materials at ETH Zurich in Switzerland.

**Thin-film Li batteries**

Materials and device engineering of on-chip high-power-density thin-film Li batteries.

**Solid Li batteries**

Interface engineering to enhance the performance of solid-state Li-batteries.
Taşan joined the MIT Department of Materials Science and Engineering as the Thomas B. King Career Development Professor of Metallurgy in January 2016. Higher performance metallic materials are needed to design more durable bridges, energy-efficient buildings and lighter-weight cars. However, the environmental side effects of metals production, specifically, those due to carbon-dioxide emissions, set new constraints in metals designs. Prof. Cem Taşan addresses these challenges by providing a deeper understanding of metal physics and developing novel alloy design concepts for longer lasting, resettable or self-healing metals. Recent work in his group also involves bone-inspired nanolaminated steel design. A native of Turkey, Taşan was previously a group leader in Max-Planck-Institut für Eisenforschung in Germany.
Bilayer Kagome Lattice Structure
Quantum Materials

Assistant Professor of Physics Joseph G. Checkelsky blends materials science and solid-state physics to uncover new electronic properties. The Checkelsky Lab works at the intersection of correlated electrons and electronic topology towards realizing emergent properties in quantum materials. The lab synthesizes materials using bulk single crystal and epitaxial thin film growth techniques and studies them with transport, thermodynamic, and spectroscopic probes. The goal of this work is to uncover fundamentally new electronic behavior that may enable new functionalities for the next generation of electronics. He is a participant in the Center for Integrated Quantum Materials (CIQM) and one of the organizers of the Quantum Science Summer School (QS3). He collaborates actively with the experimental and theoretical condensed matter researchers of the Physics Department and of the Department of Materials Science and Engineering. Checkelsky joined the Department of Physics at MIT in January 2014.
Quantum Transport in Graphene
Quantum Optoelectronics

Associate Professor of Physics Pablo Jarillo-Herrero conducts experimental research in condensed matter physics, in particular, quantum electronic transport and optoelectronics in novel low dimensional materials, such as graphene and topological insulators. He received his M.Sc. in physics from the University of Valencia, Spain, and a second M.Sc. degree at the University of California in San Diego. He earned his Ph.D. at Delft University of Technology in The Netherlands in 2005. After a one-year postdoc in Delft, he moved to Columbia University, where he worked as a NanoResearch Initiative Fellow. His awards include the Spanish Royal Society Young Investigator Award, an NSF Career Award, an Alfred P. Sloan Fellowship, a David and Lucile Packard Fellowship, the IUPAP Young Scientist Prize in Semiconductor Physics, a DOE Early Career Award, a Presidential Early Career Award for Scientists and Engineers, and an ONR Young Investigator Award. Jarillo-Herrero joined MIT as an assistant professor of physics in January 2008.

Tuning ultrafast electron thermalization pathways in a van der Waals heterostructure