Center for Materials Science and Engineering

The Materials Research Science and Engineering Center (MRSEC) at MIT, funded by the National Science Foundation (NSF), was established in 1994 as the core program of the Center for Materials Science and Engineering (CMSE). In September 2008, NSF awarded CMSE a renewed six-year $19.2 million MRSEC center grant to fund CMSE's research and educational outreach programs as well as its shared experimental facilities from September 2008 to August 2014. This award is the culmination of an extensive two-year internal and external review process and preparation of proposals at CMSE headquarters that enabled CMSE to compete with over 100 other national institutions to win one of 14 NSF MRSEC center awards for this six-year period.

CMSE promotes and facilitates interdisciplinary research and education in the science and engineering of materials. MIT has an exceptionally strong and broad effort in materials science and engineering involving more than 160 faculty members in 14 different departments in the School of Engineering and the School of Science. CMSE plays the critical role of bringing this diverse materials community together by encouraging and supporting collaborative research and innovative educational outreach programs and by providing state-of-the-art shared experimental facilities (SEFs). The clear and important mission of CMSE is to enable—through interdisciplinary fundamental research, innovative educational outreach programs, and directed knowledge transfer—the development and understanding of new materials, structures, and theories that can impact the current and future needs of society. The complexities of such research clearly require input from industry and the expertise of many faculty working collaboratively in a team-based approach. To accomplish this important mission, CMSE enables collaborative, interdisciplinary research among MIT faculty and among MIT faculty and researchers from other universities, industry, and government laboratories.

CMSE promotes collaborative research through several mechanisms: interdisciplinary research groups (IRGs), seed and initiative projects, SEFs, and outreach programs. While seed funding preference is given to young faculty, CMSE uses seed and initiative funds to support research that has the potential of redefining the direction of an existing IRG or leading to the creation of a completely new IRG. Seed funding provides CMSE with the flexibility necessary to initiate high-risk, transformative research. Our research programs typically support a total of 30 to 40 faculty members from 10 or more departments. Over the life of our recently ended 2002–2008 MRSEC grant, our CMSE faculty published 645 papers in which research results were either primarily or partially supported by MRSEC funding or related to our SEFs and awarded 91 patents. During the first nine months of our new 2008–2014 MRSEC award, researchers published results in 17 papers and were awarded five patents related to their MRSEC research.

Our SEFs are used by numerous research groups from MIT as well as by outside academic and industrial communities. During the March 2008 to February 2009 period, 926 people used our SEFs, including 689 students and postdocs of 96 MIT faculty in 23 academic departments, labs, and centers; 71 students and staff of faculty from 14 outside academic/research institutions; 150 students from MIT lab subjects; and 16 staff of senior-level industrial managers.

Our educational outreach programs encompass a broad range of activities and age levels, with participation from K–12 students and teachers and undergraduates from other institutions. Last year, 110 people participated in our various core programs with support from CMSE-funded faculty, graduate students, and postdocs. CMSE MRSEC faculty also devoted many hours to tutoring students, making presentations to students and teachers, supervising high school students in their labs, and hosting groups of students visiting CMSE labs. In addition, more than 700 people attended workshops and public events in which CMSE took part.

New Interdisciplinary Research Programs and Scientific Accomplishments

The past year was one of transition as CMSE brought its 2002–2008 MRSEC research program to a close and began a completely new research program under the new 2008–2014 MRSEC grant.

The new MRSEC grant supports three IRGs, two initiative projects, and five seed projects involving 30 principal investigators. These groups and their FY2009 results are summarized below.

IRG-I: Design of Nanomaterials for Electrochemical Energy Storage and Conversion

The objective of this IRG is, on the one hand, to use electrochemistry to accurately determine how thermodynamics, phase stability, and kinetics are modified at the nanoscale, and, on the other hand, to apply that knowledge to engineer materials with high-energy, high-power Li storage capabilities and design nanocatalysts with superior oxygen reduction reaction activity and reduced noble metal content. The supply of sustainable energy is arguably the most important scientific and technological challenge in the 21st century. Meeting this challenge will require not only increased energy efficiency but also new energy storage platforms to displace existing carbon-based fuels with carbon-neutral energy such as solar energy. Electrochemical devices such as Li batteries and fuel cells that operate on hydrogen produced from solar energy are promising technologies to buffer the supply and demand of energy, particularly for portable power and hybrid propulsion in transportation. Meeting the demands of these applications requires new ideas to design materials with tailored reactivity toward lithium for Li batteries and catalysts with markedly higher activity toward oxygen reduction reactions in fuel cells.

Faculty participants and department affiliations: G. Ceder, coleader (Materials Science and Engineering [DMSE]); Y. Shao-Horn, coleader (Mechanical Engineering); A. Belcher (DMSE and Biological Engineering); K. Hamad-Schifferli (Mechanical Engineering and Biological Engineering); N. Marzari (DMSE); and C. Thompson (DMSE).

FY2009 IRG-I Results

IRG-I members have leveraged earlier theoretical predictions by the group that suggested that extremely high lithium ion speeds are possible in lithium iron phosphate battery materials ($LiFePO_4$) to create batteries with amazingly fast charging/discharging times. By changing the surface structure of this material, it was shown that it is possible

to realize experimentally the predicted high power rates. Such high rate materials can be valuable in everything from rapidly charging cell phones to high-powered hybrid and plug-in hybrid vehicles. IRG-I research has also correlated the surface characteristics of Pt nanoparticles with the intrinsic activity of carbon monoxide and methanol electro-oxidation. This research suggests that increasing step densities on Pt nanoparticles can enhance specific activity up to 200%, translating to a reduction in Pt weight of up to 200% for a given fuel cell current output. Bio-derived gold nanowires of interest due to their potentially large electrocatalytic activity have been prepared from a genetically engineered virus with 2,700 copies of a specific gold binding sequence. This approach opens the door to the low-temperature creation of nanostructured gold with tunable dimensions and properties.

IRG-II: Mechanomutable Heteronanomaterials

This IRG proposes to develop a new class of "mechanomutable heteronanomaterials," which we define as possessing spatially localized and controlled nanoscale units of different types of materials that change their mechanical properties reversibly in response to an external stimulus. This research will significantly advance the existing body of literature on responsive materials, which are typically single- and two-component systems (e.g., hydrogels, magnetorheological elastomers, shape memory alloys, piezoelectrics) that have been focused on actuation, swelling, and controlled permeability. The use of heteronanostructures provides many exciting possibilities for mechanomutable materials design that have not yet been realized, in particular high-spatial-resolution interactions with nanoscale objects and unique and amplified mechanical robustness. For this reason, we plan to explore the possibility of utilizing these materials as high-throughput, high-spatial-sensitivity tunable sensors (e.g., for cells, proteins, localized impacts, and pressure in liquids).

Faculty participants and department affiliations: R. Cohen, coleader (Chemical Engineering); C. Ortiz, coleader (DMSE); M. Boyce (Mechanical Engineering); M. Buehler (Civil and Environmental Engineering); P. Hammond (Chemical Engineering); and K. Van Vliet (DMSE).

FY2009 IRG-II Results

IRG-II research has revealed, through atomistic-based multiscale simulations, that the concept of "mechanomutability" (i.e. the capability of a material to change its mechanical properties reversibly in response to an external stimulus) is indeed realizable. By using a model system of a surface-anchored array of carbon nanotubes, it was shown that, under the application of an external magnetic field, dramatic conformational changes occur that lead to variations in spatial patterning and a contact stiffness that can be changed reversibly from approximately 73 MPa to 910 MPa. Mechanomutable materials have many potential applications, including control of cellular behavior, modulation of protein adsorption, creation of nanoscale motors, tunable vibration absorption, and high-spatial-sensitivity variable sensors. Experimentally addressable mechanomutable materials have been created by using a templated layer-by-layer assembly approach. The resultant surface array of polymer nanotubes was found to exhibit a reversible pH-controlled swelling transition that produced significant changes in the shape, size, and physical properties of the nanotubes.

IRG-III: Multimaterial Multifunctional Nano-Structured Fibers

This IRG will explore the materials science, design, fabrication, characterization, and potential identification of novel physical phenomena of a truly unique class of fiber materials systems that are composed of conductors, insulators, glassy semiconductors, and especially crystalline semiconductors with more than 10 nanometer feature sizes. The uniqueness of our materials science approach should ultimately enable the creation of fiber structures. These fibers, while comprising all of the essential crystalline semiconductor device attributes, will be processed using conventional fiber draw processing approaches, thus yielding kilometers of fiber structures with engineered electronic, optical, thermal, and acoustic properties and exploiting photonic bandgap phenomena wherever needed.

Faculty participants and department affiliations: Y. Fink, coleader (DMSE); M. Soljačić, coleader (Physics); J. Joannopoulos (Physics); S. Johnson (Mathematics); and E. Ippen (Electrical Engineering and Computer Science [EECS]).

FY2009 IRG-III Results

IRG-III researchers demonstrated a new phenomenon in which a semiconductor cylindrical shell (inside of a fiber preform) undergoes a scaling process and evolves into an array of filaments during the fiber drawing process. This approach will allow, for the first time, the creation of fibers with a high density of electrical interconnects that may be potentially useful in enabling diverse large-area applications including energy-related technologies such as photovoltaics and thermoelectrics. Spontaneous cascaded Raman amplification was also demonstrated by this group as a practical and efficient means of power transfer from telecommunications wavelengths to mid-IR wavelength bands through use of conventional silica fibers and amplifiers. The fundamental mathematical basis for single-polarization polarization-maintaining fibers was also identified, potentially leading to new classes of photonic-crystal fibers that operate in a single-polarization regime.

Initiative-I: Engineering Living Cells via Nanomaterials

This initiative will develop a fundamental, generalizable understanding of how nanoparticles and polymer multilayers can be designed to integrate with living cells in ways that preserve cell viability and cellular processes while allowing materials to carry out engineered functions. These basic principles will enable rational selection of nanomaterials for diverse applications (such as drug delivery, tissue engineering, lab-on-chip/microfluidic technologies, biosensors and medical imaging, and therapeutic strategies based on nanomaterial-modified cells), suggest directions for the development of new materials for these applications, and allow us to systematically explore societal concerns relating to the potential toxicity of nanomaterials in vivo. Furthermore, the new materials developed in this work will expand our understanding of synthetic nanomaterial structure/property relationships per se.

Faculty participants and department affiliations: D. Irvine, coleader (DMSE and Biological Engineering); M. Rubner, coleader (DMSE); M. Bawendi (Chemistry); and F. Stellacci (DMSE).

FY2009 Initiative-I Results

Initiative-I researchers have developed a number of new processes for attaching nanoscale elements onto living immune system cells. In one case, nanoscale thickness polymer backpacks that can be loaded with a wide range of functional materials, including cancer drugs, imaging molecules, and magnetic nanoparticles, have been attached to living B-cells, T-cells, and phagocyte cells. After attachment, all cell types were found to remain viable and, since only a portion of their cell surface had been occluded by the backpack, were able to carry out their normal functions such as cell migration. In the second case, "lipid-enveloped" biodegradable polymer nanoparticles with the ability to encapsulate drug molecules in their core and/or incorporate drugs in the surface lipid bilayer were attached to living T-cells by a directed thiol reaction scheme and were not endocytosed but remained on the cell surface. Although still in the early stages of development, these experimental findings in total suggest the exciting possibility of having immune system cells selectively target, carry, and deliver therapeutic drugs to disease sites.

Initiative-II: New States of Frustrated and Correlated Materials

This initiative will focus on materials based on two-dimensional triangular and kagomé lattices, an area we pioneered as a small initiative during the previous funding cycle. Materials developed during the initiative period attracted much interest and will serve as launching points for delving further in exciting new directions, such as probing exotic states of quantum matter that contain "topological order." This new order leads to a host of fascinating properties, such as fractional quantum numbers, non-Abelian statistics, emergent photons, and more. Quantum spins on a kagomé lattice may exhibit this novel type of topological order, which would have possible applications in quantum computing. The addition of mobile charge carriers into these systems may lead to unconventional superconductivity and non-Fermi liquid ground states. There is much interesting territory to explore once candidate samples are synthesized. Our objective is to identify and synthesize new states of matter based on frustrated spin systems.

Faculty participants and department affiliations: Y. Lee, coleader (Physics); D. Nocera, coleader (Chemistry); S. Chu (CMSE); E. Hudson (Physics); and D. Shim (Earth, Atmospheric, and Planetary Sciences).

FY2009 Initiative-II Results

Initiative-II members, along with collaborators at Brookhaven National Laboratory and Nagoya University in Japan, have developed a new methodology for probing electronic properties at the atomic scale. This new approach allows one the ability to measure with atomic precision electronic properties generally thought of as "bulk" such as the "Fermi surface" related to electron density. It is anticipated that this work will reveal a new understanding of correlated electron systems. This group also found that an organic-inorganic hybrid composed of spin-1/2 Cu ions on a structurally perfect kagomé lattice shows the absence of a spin gap or magnetic ordering down to low temperatures. However, inelastic neutron scattering measurements revealed a new twist: below $T = 2$ K, a spin excitation appears that has a characteristic energy scale of about 0.6 meV. This feature is novel, and an explanation of its origins requires additional theoretical insight as well as further experimental investigations.

2008 Seed Competition

During the fall of 2008, the center conducted an Institute-wide competition for new seed proposals with funding to begin on March 1, 2009. A total of 15 proposals from six different MIT departments were received by the January 15, 2009, deadline. The proposals were distributed to the CMSE Internal Advisory Committee for recommendations to the director on funding. The goal of this funding is to support research that has the potential to redefine the direction of an existing IRG or initiative project, to lead to the creation of a completely new IRG or initiative project, or to foster a newly appreciated opportunity for high scientific discovery or technological impact. Five projects were chosen to receive $70,000 per year for two years. The research is summarized below.

Seed I: Nanoparticle Control and Transport Using Mobile Magnetic Domain Wall Traps

This research seeks to develop an on-chip system for the capture, manipulation, and transport of individual magnetic nanoparticles for applications in such areas as magnetic sorting of biomolecular entities. It is expected that a working prototype of a nanoparticle transport system with integrated single-particle detection will be developed and demonstrated. The results are widely relevant to a variety of key research areas including cell sorting, pathogen detection, chemical and biological agent detection, and controlled nanoscale assembly. Faculty participant and department affiliation: G. Beach (DMSE).

Seed II: Ultrafast Dynamics of Low Energy Excitations in Frustrated Materials

The goal of this seed project is to understand the emergent macroscopic properties of magnetically frustrated materials by studying the dynamics of their low energy excitations and phase transitions with the use of novel time resolved techniques. In these experiments, the material is excited by an ultrashort laser pulse, and the recovery of the resulting state back to the ground state is probed with femtosecond temporal and sub-Angstrom spatial resolutions. The principal investigator has developed different methods to selectively generate and probe charge, spin, or lattice excitations in quantum materials. The information that will be obtained from these measurements will help us to understand the properties of the ground state (i.e., test whether a spin liquid behavior is realized), low energy excitations, and phase diagrams. Faculty participant and department affiliation: N. Gedik (Physics).

Seed III: Tailoring Optical Properties of Semiconductor Nanomaterials

This project will concentrate on direct correlation of structural/optical properties with high spatial resolution, where semiconductor nanowires will serve as a model system. Ultimately, it seeks to answer the following questions: What are the critical structure-property relationships in semiconductor nanowires and nanowire heterostructures that govern electrical and optical properties on the nanoscale? How can this knowledge be used to predict and tailor properties of semiconductor nanowires (materials-on-demand) for specific applications in nanophotonics and nanoelectronics? Faculty participant and department affiliation: S. Gradečak (DMSE).

Seed IV: Suspended Graphene Devices for Quantum Electronics and Nanosensing

The objective of this seed project is to investigate electronic transport in ultra-high-mobility suspended graphene devices (GDs), both to study fundamental quantum electronics and to assess their potential as chemical and mass nanosensors. A crucial element of this research is the fabrication of high-quality suspended GDs. Multiterminal devices will be used to study fundamental quantum phenomena, such as the fractional quantum Hall effect or the spin Hall effect, while high-quality suspended GNRs will be actuated as tunable high-frequency nanoresonators. In addition, the possibility of passivating the edges of GNRs with desired chemical groups will enable ultra-sensitive chemical and mass detection. Faculty participant and department affiliation: P. Jarillo-Herrero (Physics).

Seed V: Large Area, Few-Layer Graphene Films for Various Applications

Graphene is the hexagonal arrangement of carbon atoms forming a one-atom thick planar sheet. This layer is the building block of graphite and carbon nanotubes, and it has been studied widely by theorists since the middle of the last century. Graphene sheets show great potential as another materials option for electronics applications. The overall goal of this seed project is to engineer the underlying metal substrate to achieve regular grain boundaries and facilitate graphene films with controlled morphology. Faculty participant and department affiliation: J. Kong (EECS).

Accomplishments of the 2002–2008 MRSEC Research Program

The MRSEC 2002–2008 research program, which drew to a close during the past year, achieved ambitious goals and performed world-class research. Important results are briefly summarized below.

Our microphotonics interdisciplinary research group (IRG-II) played a world-leadership role in the emerging field of microphotonics. By predicting and ultimately demonstrating numerous novel optical phenomena and mechanisms for the control of light using photonic crystal systems, this IRG fueled the rapid development of microphotonic theories, materials, and related technologies. Indeed, technology based on fundamental studies carried out within our MRSEC is now saving lives at hospitals across the country: over 175 novel endoscopic surgical procedures per week are being carried out across 250 medical facilities in the US using high-power laser radiation delivered by OmniGuide photonic fibers. The first of these operations was conducted on November 19, 2004. This new technology evolved directly from IRG-I fundamental research. The patient's growths in the larynx and trachea were cleared using a CO_2 laser delivered endoscopically with a photonic bandgap fiber created by OmniGuide Inc., a company that was launched on a technology platform originating from basic research carried out in MRSEC. The company was founded by Professors Fink, Joannopoulos, and Thomas of the MRSEC program. The OmniGuide Fiber surgical tool is now being used in a wide variety of medical areas beyond laryngology, including general head and neck, otology, oncology, pediatrics, and neurology. The response from surgeons has been extremely positive. For example, according to Raphael Bueno, MD, a thoracic surgeon at Brigham and Women's Hospital, "the OmniGuide Fiber gives us a

tremendous advantage in treating lung cancer patients, many of whom have limited options because of the sensitive locations of their tumors." Stanley Shapshay, MD, an otolaryngology surgeon at Albany Medical Center, noted that "for 25 years, we waited for a flexible delivery system for CO_2 lasers." This group also established the theoretical design, fabrication, and characterization of the first optoelectronic fiber that integrates conducting, insulating, and semiconducting materials.

Researchers in our nanostructured polymers interdisciplinary research group (IRG-II) have played a seminal role in defining and shaping the fundamental and technological landscape of the exploding area of polyelectrolyte multilayer assemblies. Key fundamental studies in this area have led to a range of diverse applications currently under commercial development, including antibacterial films, dielectric mirrors and rugate filters, anti-fogging coatings, and superhydrophobic coatings. The new technologies suggested by these discoveries are now being developed into commercial products by five different companies. IRG-II researchers have also pioneered methods to control block copolymer thin film morphology, orientation, and long-range order. They were the first to predict and demonstrate control of nanodomain morphology and orientation by tuning the film thickness and substrate/film interactions, exploit substrate topography to control nanodomain morphology, and employ directional solidification to create films with a high degree of long-range order. In addition, this group first achieved the utility of block copolymer films as nanolithographic templates for high-density magnetic storage and developed a completely new class of polymeric materials termed "baroplastics," polymers that do not require elevated processing temperatures to mold. This new family of plastics could substantially lower energy consumption related to plastics manufacture and save energy consumed in raw material production, since the new plastics are also highly recyclable.

The mesoscopic semiconductor and magnetic structures research of IRG-III established, through novel synthesis and thorough characterization, the importance of a new type of nanocrystal: CdSe (ZnS) core-shell nanoparticles. These new materials have become the standard building block nanocrystals in studies and applications using nanocrystal fluorescence and have set the stage for the exploitation of nanoparticles as quantum dot bioconjugates. This group made seminal synthetic advances in the creation of semiconductor nanocrystals and has developed a rigorous physical understanding of the electronic and optical properties of these new materials and their assemblies. As a result, this IRG has helped spawn numerous parallel efforts throughout the country, and indeed throughout the world. There are now a number of startup companies that are selling nanocrystals based on the synthesis developed within the IRG and devoting resources to commercializing applications ranging from bioimaging to electronics and optics. New processing schemes developed by this group allowed for the creation of new electronic memory elements and ultrathin photodectors. In addition, these pioneering processing techniques were used to demonstrate various high-efficiency, nanocrystal-based light emitting devices.

Our interdisciplinary research group exploring solid-state portable power sources (IRG-IV) pioneered the use of first principles modeling of electrode materials for rechargeable lithium batteries. As a direct result of this work, first principles modeling is now practiced in major battery and materials supplier companies around the world.

At the fundamental level, IRG-IV research clarified the relation between the electronic structure of Li-intercalation materials and their engineering properties, such as electrode voltage, Li diffusion rate, phase stability, and capacity. Through this research, it has been demonstrated that new battery electrode materials with significantly enhanced capabilities including higher charging rates and improved stability can be predicted theoretically and subsequently synthesized and evaluated. In collaboration with scientists from the State University of New York at Stony Brook, this group demonstrated that a modified crystal structure of $Li(Ni_{0.5}Mn_{0.5})O_2$, a material that exhibits high energy density but loses almost all of its storage capacity when charged quickly, exhibits more than a tenfold increase in its capacity under high rate conditions. Because this material does not contain cobalt, a relatively expensive element present in current battery materials, it has the potential to be a safer, nontoxic, and inexpensive battery material for use in hybrid electric cars.

In addition, our unique crystal growth capability enabled a number of important advances in our correlated electrons initiative. Theorists have predicted a new state of matter called the "quantum spin liquid" in which spins fluctuate in unusual ways. It is believed that a spin-1/2 kagomé lattice (composed of corner sharing triangles) is an ideal system to look for spin liquid physics because of the high degree of spin frustration. Despite intense theoretical interest, experimental studies of the spin-1/2 kagomé lattice have been hampered by the difficulty in synthesizing and characterizing such materials. This group synthesized and studied such a system (results were published in *Physical Review Letters*, Vol. 98, No. 10, 2007). They succeeded in transforming the compound clinoatacamite into an ideal kagomé lattice material called herbertsmithite. Susceptibility and specific heat measurements, as well as inelastic neutron scattering measurements, suggest that an unusual spin-liquid state with essentially gapless excitations is realized in this kagomé lattice system. This discovery was highlighted in the February 2007 issue of *Physics Today* in the article "New Candidate Emerges for a Quantum Spin Liquid."

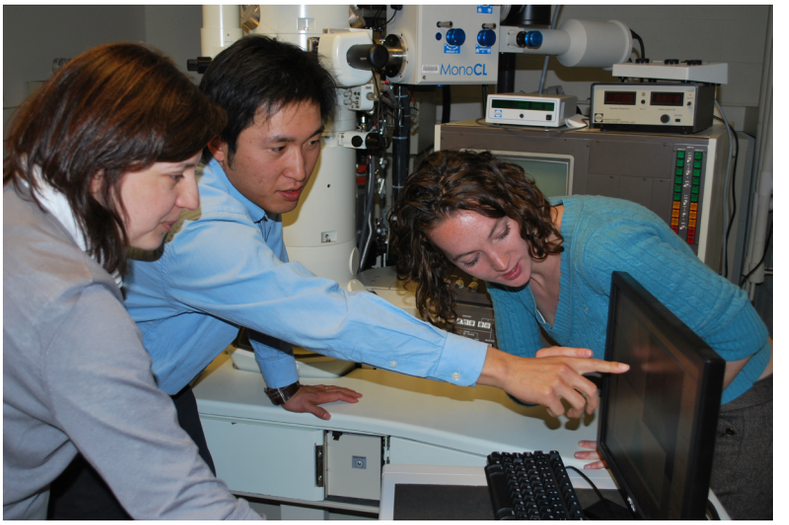
Shared Experimental Facilities

Our SEFs are a critically important resource to our MRSEC program and to the MIT community, as well as a number of outside academic and industrial organizations. Currently we run four major facilities: Materials Analysis, Crystal Growth and Preparation, Electron Microscopy, and X-ray Diffraction. These facilities are staffed by a team of highly motivated professionals. During the year ending February 2009, 926 different individuals used our facilities.

Beyond the special role our SEFs play in the training and education of MIT students, they are also an important part of CMSE's education programs. Undergraduates participating in the summer internship programs (Research Experiences for Undergraduates [REU] and Community College Students) are trained to use equipment in the SEFs to conduct their research. Teachers in the Materials Research Experience for Teachers (MRET) 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. Finally, the SEFs are included in visits to CMSE by various groups of middle and high school students.

Key activities during the past year are highlighted below.

During this period, the process of equipping the JEOL 2011 TEM/STEM with a Gatan catholuminence (CL) system was completed. The CL-STEM system enables characterization of nanostructured materials via electron-excited optical transitions with spatial resolution that is unattainable with any other technique and is unique in an academic setting in North America. The purchase of this instrument was instrumental in attracting a top-quality female faculty member, professor Silvija Gradečak, to MIT. The results from the Gradečak lab on high-resolution optical studies of GaN-based nanowire heterostructures using this system were presented as invited talks at the Materials Research Society 2008 fall meeting, at the Oak Ridge National Laboratory, and on a poster for the October 2008 Materials Day at MIT. Professor Gradečak has also been invited to present a talk on the subject of cathodoluminescence at the upcoming Frontiers of Electron Microscopy and Materials Science conference (September 27–October 2, 2009) in Sasebo, Japan. In addition, Megan Brewster, a graduate student from the Gradevak research group, presented CL results at the XVI Microscopy of Semiconducting Materials Conference that took place in Oxford, England, from March 17–20, 2009.



Professor Silvija Gradečak and students Megan Brewster and Sung Keun Lim use the CL-STEM.

After extensive input from an ad hoc committee of MIT faculty, a poll of our MIT user community, and a complete review by the CMSE Internal Advisory Committee, a decision was made to purchase a dual-beam focused ion-beam milling system (FIB) from FEI. This instrument, not one currently available to the MIT user community, will be used for preparation of transmission electron microscopy (TEM) specimens, for nanolithography, and for serial sectioning and subsequent 3D reconstruction of solid samples. It was delivered in June of 2009 and is expected to be fully operational by October 2009.

From October 20–23, 2008, Dr. Scott Speakman of the X-ray Diffraction Facility was a guest instructor at a workshop on Rietveld refinement of X-ray diffraction data using the HighScore Plus program; the workshop, offered by PANalytical Inc., was held in Westborough, MA. The class was attended by 16 professionals from universities and organizations such as the University of Kentucky, Pennsylvania State University, Centro de Investigación en Materiales Avanzados (Chihuahua, Mexico), the US Air Force Academy, the US Geological Survey, Navair, Teck Cominco Metals Ltd., Ferro

Inc., World Minerals Inc., Ceramatec, Johnson Matthey Inc., and Intrepid Potash. Free attendance was provided for three MIT graduate students. In addition to offering a service to the community at large, Dr. Speakman's involvement as an instructor in this course resulted in better dialogue with the developers of the analytical software used and translated into better experience in teaching these techniques to CMSE users.

A number of vendor-presented seminars and/or demonstrations were organized or sponsored by CMSE. Companies involved included Qsense, FEI, and Veeco. Qsense sent two representatives, Stephen Hussey (national sales manager) and Goran Zelander (an applications specialist visiting from Sweden), to MIT on October 21, 2008, to hold a meeting/workshop on the use of the Quartz Crystal Microbalance with Dissipation. Hussey demonstrated the instrumentation and fielded users' questions, while Zelander worked with users who had already collected data and had questions on data analysis. On October 7, 2008, Dr. Lucille Giannuzzi from FEI gave a talk titled "Introduction to Focused Ion Beam Technology." The talk, arranged by the CMSE Electron Microscopy Facility, was advertised campuswide and a group of 30 students and postdoctoral associates attended. During the January 2009 Independent Activities Period (IAP) session, Veeco Metrology presented a two-day workshop on electrical characterization techniques using the NanoScope V atomic force microscope (AFM). A total of 15 students and postdoctoral associates attended this session in the Analytical Facility.

Our SEF staff has been an important element of many of our educational outreach programs and enthusiastically embraces this role. For example, our staff play a special role in the training of MIT graduate and undergraduate students and our summer educational outreach participants. During this academic year, 150 undergraduate students used the facilities as part of their laboratory subjects.

On October 29, 2008, the SEF staff hosted a group of 30 students from cell biology and biotechnology classes at Bunker Hill Community College (BHCC) for tours of the Materials Analysis, Electron Microscopy, and X-ray facilities and demonstrations of AFM, X-ray, scanning electron microscopy (SEM), and TEM techniques. The group ended the day with a meeting and discussion time with the CMSE director. A similar type of visit for 18 additional students from BHCC took place on April 29, 2009.

SEF staff members offered a number of mini-courses during MIT's 2009 IAP to train students to operate SEF equipment and apply the latest techniques to their research problems. In January of 2009, a total of 72 students and postdoctoral associates attended courses taught by the SEF staff. One very popular course was Introduction to Transmission Electron Microscopy, taught by Dr. Yong Zhang. The 17 attendees included students, postdoctoral researchers, and visiting scientists. This lecture provided an introduction to the fundamental principles of TEM. Topics covered were the illumination system, electron lenses and their aberrations, image formation, and resolution. A variety of imaging and analysis techniques and their roles specific to inorganic materials, such as crystallography, diffraction patterns, and high-resolution imaging, were presented with practical demonstrations. This presentation also introduced TEM sample preparation techniques for a wide range of materials, including metals, semiconductors, powders, and thin films.

Collaborations, Outreach, and Knowledge Transfer

Our MRSEC-supported faculty has ongoing collaborations with numerous industrial partners that range from the funding of applied projects (often based on fundamental work carried out within the center) to the development of new technologies and products. We work closely and effectively with MIT programs and centers, such as the Materials Processing Center (MPC) and the Industrial Liaison Program (ILP), which connects MIT research to industry. These organizations combined have more than 200 member companies. In the first six months of our new grant, our faculty engaged in at least 40 ILP-organized meetings with representatives from a broad range of domestic and foreign companies, including visits from industrial representatives, faculty visits to different firms, briefings to company executives, and teleconferences. A partial list of these companies includes Air Liquide, BP Solar, Bekaert, Olympus, Siemens, Eni, Michelin, Bridgestone/Firestone, Sharp, Tata Chemicals, Ciba Specialty Chemicals, Pall Corporation, Bosch, Hitachi, and Honda. CMSE director Michael Rubner gave an overview of MRSEC research at two of his industry meetings: during a videoconference with DSM of the Netherlands and at an executive briefing with Johnson & Johnson. MRSEC-supported faculty also presented an overview of their research in two ILP-sponsored conferences: the 2008 MIT Research and Development conference (professors M. Buehler, K. Van Vliet, G. Ceder, and F. Stellacci) and the 2008 MIT in Japan conference (professors D. Nocera and S. Leeb). These conferences were attended in total by more than 450 representatives from US and foreign companies including 3M, L-3 Communications Corporation, Raytheon, Hitachi, Nissan Motor Co. Ltd., Sharp Corporation, NEC Corporation, and Canon Inc.

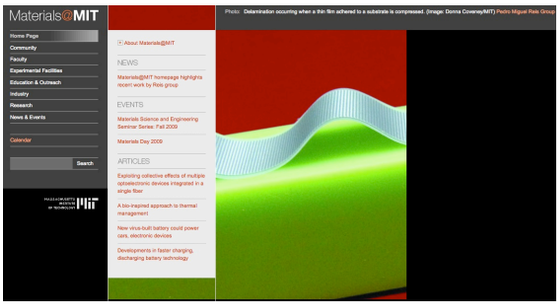
CMSE has also strengthened its involvement in one of the showcase MIT materials events, the annual Materials Day at MIT organized by MPC. CMSE now jointly sponsors this symposium and contributes significantly to its technical program. One important objective of this event is to connect MIT materials research to managers and researchers from industry and government laboratories. The theme of the 2008 Materials Day at MIT event was "Nanostructure to Infrastructure to Sustainability." CMSE speakers and moderators included Professors Irvine, Thompson, and Van Vliet. The meeting was attended by approximately 70 registered guests from industry, government laboratories, hospitals, MIT, and other universities, as well as by an additional 25–30 researchers and students from MIT who joined throughout the day on a walk-in basis. Companies represented included 3M, Analog Devices, Bose Corporation, Corning, Hewlett-Packard, Lockheed Martin, Lord Corporation, Nokia, Raytheon, Saint-Gobain, Shell Oil, and Toshiba. The capstone poster event included posters from CMSE students and others from the MIT materials science community. Students from two CMSE-supported research groups won prizes for best poster: Fernando Vasconcellos and Albert Swiston of the Cohen/Rubner group, for "Functional Polyelectrolyte Multilayer Patches on Living Lymphocytes," and Kevin Krogman of the Hammond group, for "Multifunctionalized Electrospun Materials for Toxic Chemical Protection." The poster session was judged by a panel of judges from MPC's Advisory Board.

CMSE is also continuing its joint colloquium series with the Department of Materials Science and Engineering and the Materials Processing Center. This partnership allows us to pool resources and bring in speakers from outside MIT. Objectives of the colloquium

series are to provide opportunities for faculty, research staff, and students from different disciplines to meet on a regular basis to hear about the latest breakthroughs in materials research and to inform the greater MIT community about materials research. This joint series also strives to promote inter-MRSEC knowledge transfer.
These lectures typically drew audiences of 60–100 people. Paul McEuen (Cornell MRSEC), Taeghwan Hyeon (Singapore National University), Ken Sandhage (Georgia Tech), Chekesha Liddell (Cornell MRSEC), and Izabela Szlufarska (University of Wisconsin MRSEC) spoke in fall 2008. In spring 2009, the speakers were Monica de la Cruz (Northwestern University MRSEC director), Frans Spaepen (Harvard MRSEC), David Seidman (Northwestern University MRSEC), Matthew Doty (University Of Delaware), and David Smith (Duke)

CMSE-supported work was on display at the third annual "Energy Night" poster session, sponsored by the MIT Energy Club. This student-organized event showcases MIT's most exciting work in energy: research, startups, and campus initiatives. Students from the Ceder group presented a poster titled "Computational Materials Design for Photovoltaic and Other Energy Applications," and students from the Hammond group presented a poster titled "Layer-by-Layer Assembled Proton Exchange Membranes for Fuel Cells." Both posters highlighted MRSEC-sponsored research.

We continue to enhance our knowledge transfer and outreach capabilities through the MIT-wide materials website and a completely revamped CMSE MRSEC website. In the former case, a collaborative effort involving MPC and DMSE resulted in the launch (in October 2006) of the Materials@MIT gateway website (http://materials.mit.edu/). This website provides a single point of access to information on the various researchers, departments, labs and centers, educational opportunities, and SEFs on campus that are involved in materials research. A key feature of the site is a database of all materials-related shared equipment at MIT, including all CMSE user equipment.



Screen capture of the Materials@MIT homepage in August 2009.

The CMSE MRSEC website (http://web.mit.edu/cmse/) presents a well-organized design that facilitates access to important research information such as "hot articles," nuggets, and new research developments. In addition, there is a section under Educational Outreach for downloading teaching modules and lesson plans.

Another important mechanism for knowledge transfer is the creation of new companies and businesses (and related jobs). Currently active CMSE-related companies that were started by MRSEC faculty, students, or postdocs include OmniGuide Inc., LumArray, Luminus Devices Inc., QD Vision, and three recent startups: Kateeva, WiTricity Corporation, and Svaya Nanotechnology. Kateeva was started in 2008 by professor Vlaidimir Bulovic (supported by our previous MRSEC award) and several of his MRSEC-funded group members, along with MIT professor Martin Schmidt. The mission of Kateeva is to commercialize a new technology that could radically change

manufacturing in the flat panel display industry and enable displays that are thinner, brighter, lighter, more vivid, more power efficient, and less expensive than what is possible today. The company is located in Menlo Park, CA. WiTricity Corporation, founded in late 2007, continues to commercialize a new technology for wireless electricity pioneered by MIT professor Marin Soljačić. The company is located in Watertown, MA. The newest CMSE-related startup, Svaya Technologies, was founded by professor Paula Hammond and colleagues in September 2008. This Boston-area company will commercialize a new thin film manufacturing process that is more flexible and scalable than existing methods. The technology is based on an aqueous solution self-assembly process that emerged, in part, from layer-by-layer research pioneered by an IRG funded during the previous MRSEC grant (IRG-II).

These various companies were founded to develop novel devices and components based on discoveries made within the MRSEC program and funded, in several cases, exclusively through NSF. Additionally, Nanosys and Quantum Dot Corporation (bought by Invitrogen) are companies whose technology platform is based in part on CMSE-supported fundamental research. We estimate that total direct job creation by the seven most closely CMSE-related companies is about 340 jobs to date.

MIT's Technology Licensing Office (TLO) is kept aware of new discoveries emanating from CMSE research and helps researchers file patents and issue licenses. Since the start of the new grant period, five new patents have been issued, and eight new patent applications/provisional patents are pending that are related to MRSEC. In addition, there are currently 21 active industrial, academic, and governmental licenses of CMSE-patented research (including two new licenses from the current grant period).

The center's MRSEC-supported faculty enjoy a high level of outside collaboration. During this academic year, there were 10 MRSEC-related industrial collaborations, 23 collaborations with outside academic researchers, and 11 collaborations with government laboratories and agencies. In addition, a number of CMSE faculty members supervised students in departmental co-op programs that carry out research projects in a wide variety of industrial laboratories.

Education and Human Resources

CMSE 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. We have now put in place a broad range of well-received programs that impact high school students and teachers as well as undergraduate and graduate students. Our programs are managed by a full-time education officer who works closely with a faculty education program leader, the center director, and the assistant director. In addition, the center's Educational Outreach Committee consults on the direction of the education programs and the coordination of those programs with other outreach programs on campus. The committee's membership is made up of personnel from MIT who are actively involved in educational outreach efforts, as well as Dr. Hannah Sevian, associate professor of chemistry and science education at the University of Massachusetts, Boston, and a faculty liaison at Roxbury Community College (RCC) and BHCC.

Besides involvement in CMSE's formal education activities (outlined below), MRSEC-supported faculty, research scientists, and graduate students participate in outreach activities with local schools and with religious communities and professional organizations. Our faculty reported that over the past grant period, they and their research groups devoted about 40 hours to making presentations and delivering lectures to approximately 1,200 middle and high school students and teachers.

For the past four years, CMSE has collaborated with RCC, a minority-rich two-year college in Boston, to make research experiences available to its students. The objective of this dedicated 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 BHCC as well as RCC. Both colleges have significant enrollments of minority students.

Precollege Education

Materials Research Experience for Teachers

For the past 10 years, CMSE has operated a successful MRET program. This program brings high school and middle school teachers to MIT to participate in CMSE 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 material that will transfer their research experience to their classroom teaching. The major components of the program are research, weekly discussion meetings, SEF tours, and the development of classroom materials. 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. In the summer of 2008, four new teachers worked on research and four returning teachers worked on creating classroom materials.

Relative to the program goal of producing classroom material that can be shared with other educators, lesson plans or lab experiments produced over the past year are listed below. Teachers will test these materials in classrooms over the academic year and refine them. Once finalized, CMSE will make them available on its website. The center offers each teacher a modest amount of funding for supplies to implement his or her unit.

- "Teaching Buffers: A Living by Chemistry-Style Lesson Designed to Complement the Acid-Base Lessons in the Living by Chemistry Toxins Unit" (Mary Angione, Brookline High School, Brookline, MA)
- "Using a Spectrophotometer to Measure Production of NADPH from Glucose—A Simple Way to Show the Role of Enzymes in Chemical Enzymatic Reactions" (Leonardo Medina, Lawrence High School, Lawrence, MA)
- "Characterization of a Magnetic Shake Flashlight" (Sean Müller, Merrimack High School, Merrimack, NH)
- "Turbines for Teachers" (Becky Paysnick, Curley K-8 School, Jamaica Plain, MA)

Feedback from recent participants in the MRET program indicates that they were satisfied with the program and that it has had a meaningful impact on their teaching. The most frequently cited enhancement of their classroom teaching as a result of their research experience at CMSE is the incorporation of more hands-on lab projects. The program participants often share their units and MRET experience with fellow teachers at their schools and at regional and national meetings.

Science Teacher Enrichment Program and Women's Technology Program

CMSE offered its Science Teacher Enrichment Program (STEP) for the seventh time in the summer of 2008. The goal of the program is to deepen the teachers' content knowledge in areas related to the state learning standards. It consists of a one-week, hands-on workshop, "Dustbusting by Design," in which the participants enhance their knowledge of the engineering design process by immersing themselves in it. After considering the special features of a hand-held vacuum, the physics of its operation, and the properties of the materials involved, the participants design and construct motors to meet performance specifications. The program includes presentations on polymers and new battery materials. The final day is devoted to a brainstorming session among the teachers and professor Steven Leeb, CMSE's faculty education leader, about classroom projects to transfer the teachers' experience to their students.

A companion effort to STEP is CMSE's collaboration in the Women's Technology Program (WTP) in EECS. In this four-week summer residential program, 40 high school girls from across the country take classes in math, computer science, and engineering. The program is designed to address a gender imbalance in the field of engineering by increasing the girls' interest and confidence in pursuing engineering careers. CMSE invites the WTP participants to join the lab portion of STEP to gain hands-on engineering experience. For the past seven years, this has been an extremely successful collaboration. WTP alumni report that this motor-building lab is an exciting part of the program. CMSE continued to support WTP by providing the curriculum and supplies for this part of their program in 2008 and will continue to do so in 2009.

Workshops and Public Events

During the past academic year, Professor Leeb conducted a number of short programs or workshops for K–12 students. In October of 2008, he taught a class on "Materials for Energy Conversion" to 25 second-grade students at the Winbrook School in Belmont, MA. He returned to the school in February of 2009 for "Math Night," when he led the students through an activity using Cartesian grids to locate objects on a map. This event was attended by 143 students and parents. At another event, an undergraduate, Sabrina Newman, helped lead 40 local Girl Scouts through a light-emitting devices project. Professor Leeb also spent an evening teaching a hands-on activity on electrochemistry and batteries to 14 Cub Scouts.

In the fall of 2008, CMSE participated in the Educational Studies Program's weekend SPLASH event for middle and high school students. Professor Leeb and a graduate student, Kevin Brokish, taught a class on "Materials in Energy Conversion." The 16 students who participated in this class designed and built windmills. This activity was an extension of the classroom unit on turbines done by MRET participant Becky

Paysnick in Professor Leeb's lab over the past two summers. In May, Kevin Brokish joined with another graduate student, Daniel Livengood, to teach a similar activity, "Blowing in the Wind," to 35 middle school students who participated in the Sally Ride Science Festival on campus. This annual event encourages fifth- to eighth-grade girls to pursue science. Finally, on June 22–25, Professor Leeb taught a materials and energy class to 25 high school students participating in the Research Science Institute program.

The annual citywide Cambridge Science Festival took place for the third year in April 2009. This weeklong event is widely advertised and is usually attended by hundreds of people from local communities. At the opening day "Science Carnival" portion of the festival this year, MRSEC graduate students presented a table on nanoscale materials that included posters describing their CMSE nanotechnology research, demonstrations of the synthesis of gold and silver nanoparticles, and a participatory art project that engaged attendees in "coloring" in a window with prepared gold and silver nanoparticle solutions. This activity was based on the "Nanoparticle Stained Glass" unit developed by the University of Wisconsin MRSEC and shared through NISENet.org. It is estimated that approximately 250 individuals, from toddlers to grandparents, visited the CMSE table.

Science and Engineering Program for Middle School Students

The center has operated a science and engineering program for seventh- and eighth-grade students from two Cambridge public schools for the past 17 summers. The objectives of the program are to 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 full summer week of hands-on and inquiry-based science and engineering classes for students from each school. The 2008 middle school program took place during the weeks of August 4–8 and August 11–15. Eighteen students from the Morse and Peabody schools attended with their science teachers. The group included seven boys and 11 girls. Eight of these students are members of underrepresented minority groups.

The program covers a wide variety of topics. Most activities take place during 90-minute periods, and some include multiple sessions. The 2008 program included glassblowing, polymer demonstrations, electric circuitry, metal casting, and an engineering design contest. Each year the program concludes with the "Shoot-the-Hoop" design competition, to which families of program participants are invited. Activities offered are evaluated and modified each year by Professor Leeb and the program staff. Program activities are designed and taught by MIT faculty, staff, graduate students, and undergraduates. CMSE has developed collaborative relationships with MIT's Edgerton Center, the MIT Museum, the Department of Physics, EECS, and DMSE, which contribute to the development and implementation of projects. Some activities are modified versions of material used in MIT undergraduate classes.

Undergraduate Education

Undergraduate Research Opportunities Program

CMSE continues to sponsor undergraduate involvement in MRSEC research through MIT's Undergraduate Research Opportunities Program (UROP). During the past year,

12 students (including three women and one member of an underrepresented minority group) participated in the program with support from CMSE. In addition to the students paid by MRSEC, 11 undergraduates (including five women and two minority students) conducted research with an MRSEC-funded research group on a volunteer basis or with MIT funding. Some students continued their UROP research through multiple terms.

Summer Research Internship Program

In collaboration with MPC, CMSE sponsors the Summer Research Internship Program (through the NSF REU program). The program's major goals are to provide undergraduates from other institutions an opportunity to perform cutting-edge materials research and to attract students to graduate studies in materials science and engineering. The two centers intend to continue this collaboration. The program is open to US citizens and permanent residents who will be juniors or seniors the following fall. We received approximately 150 applications for the summer of 2008, which were reviewed by a committee consisting of the CMSE director and staff from both centers. Participants were chosen from this pool on the basis of academic performance, interest statements, and faculty references. The 18 students accepted into the program for the summer of 2008 included nine women and nine men, two of whom are from underrepresented minority groups. Two of the participants were supported by the Siemens Foundation.

The students were paid stipends and worked full time for nine weeks. Most of them lived in a dormitory on campus. Weekly meetings were devoted to research discussions and informal seminars with guest speakers on topics such as the graduate school admissions process, research funding, and intellectual property. The interns completed the program by producing posters that reported on their summer's research. The resulting poster session was held during the final week and was open to the entire MIT community. It included posters produced by participants in CMSE's MRET and community college programs as well and served the dual purpose of functioning as a final report by the interns and teachers and informing the broader MIT materials community about the wide range of research supported under the auspices of the two centers.

Diversity Enhancement Activities

CMSE has a history of promoting and encouraging traditionally underrepresented minority groups and women to participate in materials research. This is accomplished through educational outreach efforts, special programs for graduate research assistants, and efforts to coordinate activities with faculty, postdoctoral associates, and graduate and undergraduate students. A few of these activities are summarized below.

Community College Partnerships

CMSE developed the Community College Program (CCP) in 2005 with RCC and in 2007 added participants from BHCC. The overall objectives of this targeted REU program are to engage community college students in current materials research, help them develop their research skills, and encourage and enthuse them to pursue four-year degrees and careers in science and engineering. The program includes participants from two local community colleges that enroll significant numbers of minority students (40% at one and 55% at the other) who do not have opportunities to gain research experience at

their home institutions. Students were chosen to participate in this program by faculty at their home institutions. Over the four-year history of the CCP, 79% of the participants have been minority students and 57% have been women. This program continues with strengthened partnerships with the two community colleges. CMSE expanded its partnership with BHCC over the past year to introduce an additional 48 students to the research tools in CMSE's SEFs. The BHCC faculty involved have indicated that this was important as it exposed their students to broader career options.

During the summer of 2008, two RCC students and three BHCC students, including one African American student and three women, participated in the program. In addition, professor Karen Atkinson from BHCC also participated in a summer research project at MIT funded through CMSE's MRET program.

The community college students spent nine weeks during the summer working on CMSE research as part of faculty-led research groups for which the students were awarded stipends. They chose their research projects from several presented by the MRSEC director during a preliminary seminar. Once on campus, the students participated in all REU meetings and activities. In addition, a separate meeting of these students and Professor Atkinson with the MRSEC director and staff was devoted to addressing their questions about research and obtaining feedback on the program. In August 2008, participants in the program presented posters on their research at the REU/MRET poster session.

The CCP students were very enthusiastic about their research experience at CMSE. One student returned in 2008 to continue the research he had begun during the summer of 2007, and two of the 2008 participants were invited by their faculty supervisor to continue on a part-time basis during the fall term. Girma Endale, an RCC student who first participated in 2006, returned for a second summer in 2008. In his valedictorian speech at the RCC graduation ceremony, he expressed his gratitude for the opportunity to be involved in research at CMSE: "That internship not only helped me to gain experience, knowledge, and motivation but also became a turning point in my life." Girma began work on a bachelor's degree at Boston University in fall 2008 and he recently informed us that he has been accepted into a master's degree program at BU.

Girma Endale delivers the valedictorian address at the Roxbury Community College graduation ceremony, June 2008.

REU Outreach to Students from Underrepresented Minority Groups

We plan to enhance participation by students from underrepresented minority groups in the REU program through targeted marketing and the development of potential partnerships with other NSF-sponsored sites.

An exciting new program in CMSE's education portfolio designed to enhance the research skills and experience of students at Puerto Rican universities is an emerging

partnership with the Universidad Metropolitana (UMET) in San Juan, Puerto Rico. The collaboration was launched with the inclusion of two UMET students in CMSE's Summer Research Internship Program during the summer of 2008. It is expected that UMET students will participate in the internship program each summer. In June of 2009, two additional UMET students spent two weeks at MIT being trained to use equipment in the SEFs as they worked with graduate student mentors on MRSEC research. The students learned to use the atomic force microscope and scanning electron microscope; they reported that the experience provided them with useful skills while opening their eyes to career possibilities in the field of materials science and engineering. A third component of the partnership will take place in December 2009, when the CMSE graduate student mentors will spend a couple of days at UMET making presentations to precollege students and teachers and training their undergraduate partners to make similar presentations throughout the year. Aside from enhancing the students' presentation skills, the objectives of this portion of the program are to broaden its impact and to recruit and retain Puerto Rican science, technology, and engineering graduates. Significant communication between CMSE and UMET has taken place to develop this program. The MRSEC director has visited UMET several times to meet with Dr. Juan Arratia, who is the director of an NSF-funded Model Institution of Excellence and is leading the effort in Puerto Rico. During his most recent visit in March 2009, Professor Rubner made a presentation on CMSE's research and education opportunities to students at the Ana G. Mendez University System Student Research Development Center. In addition, the associate dean of the Department of Science and Technology at UMET visited MRSEC in August of 2008 to learn more about the internship program and CMSE.

CMSE director Michael Rubner meets with UMET students after his presentation in Puerto Rico.

In an effort to recruit REU participants from institutions that have significant numbers of students from underrepresented groups, each year the CMSE director sends letters, brochures, and posters directly to 85 project directors of NSF-funded Historically Black College and University Undergraduate Programs, Louis Stokes Alliances for Minority Participation, and Centers of Research Excellence in Science and Technology, asking them to encourage their students to apply to the program. To date, the return on this effort has been limited.

Educational Outreach Collaborations and Materials Science Content Expansion

Other areas of effort include collaboration with other units at MIT to enhance educational outreach programs and to add materials science content to programs of other departments and centers. For many years, we have collaborated with the Edgerton Center and MIT Museum on our middle school program, school visits, and Family Adventures in Science and Technology (FAST) Sundays at the museum. We have established strong

working relationships and collaborations with other administrative units at MIT, including MPC and departments in the School of Science and the School of Engineering. The CMSE education officer participates in meetings of the Committee on MIT K–12 Educational Outreach Programs led by professors Eric Klopfer and Kim Vandiver. Information on all of the educational outreach efforts at MIT was also showcased at "Science Outreach Night," an event hosted by the MIT Museum in September 2008. CMSE's education officer participated in this event, presenting information on the center's education programs to an audience of about 200. The objectives of the evening were to make MIT students aware of opportunities to be involved in education programs and to advertise MIT's programs to the local education community.

In addition, CMSE director Michael Rubner is regularly engaged in discussions with deans and department heads concerning strategies for the recruitment and retention of postdoctoral associates and young faculty who are members of underrepresented groups. In November of 2008, Professor Rubner participated in the daylong Diversity Leadership Congress convened by MIT president Susan Hockfield.

CMSE has been very successful in offering educational enrichment opportunities to a broad and diverse range of individuals. We continue to enthusiastically support the participation of women and members of underrepresented minority groups in all of our education programs.

Graduate Education

IRGs, initiatives, and seed projects supported by CMSE include research assistantships for graduate students. Through the end of 2008, CMSE provided earmarked funds to support assistantships for graduate students from underrepresented minority groups. Three minority research assistants were supported directly by CMSE. This targeted funding was in addition to a faculty member's existing CMSE funds, providing an incentive to include minority students in his or her research group.

Postdoctoral Mentoring

CMSE supported 15 postdoctoral associates during the past year. They were mentored on a regular basis by their faculty supervisors. As part of a new CMSE mentoring plan, the director will meet with the postdocs as a group to discuss their research activities, career paths, and professional progress. The director will also invite CMSE faculty to give presentations on important career challenges such as how to write a research proposal, how to interview for both industrial and academic positions, and how to organize and manage a research group. In addition, the postdocs will be encouraged to refine their communication and teaching skills through participation in professional events such as Materials Day at MIT and in CMSE's education programs.

Administration, Management, and Research

Our MRSEC program is administered by a proactive and effective management team that responds quickly to emerging needs of the program. Currently, seven administrative and seven SEF staff support the program. Administrative staff include an education officer, facilities and safety coordinator, financial administrator, financial

and operations assistant, assistant to the director, assistant director, and director. SEF staff include one technical associate, four research specialists, a project technician, and a research scientist. The CMSE director reports directly to the vice president for research and associate provost, the assistant director reports to the director, and all other staff, including the facilities manager, report to the assistant director. Our current director also serves as CMSE's chemical hygiene officer. At present, CMSE has a faculty education program leader who marshals our educational outreach plans with our education officer.

Dr. Tony Garratt-Reed and family celebrate his 35 years of service at MIT.

Dr. Tony Garratt-Reed, CMSE's SEF technical manager, retired in September 2008 after a 35-year career at MIT as an electron microscopist and manager in our shared experimental facilities. A reception in CMSE's von Hippel room was held on September 30, 2008, where MIT staff and faculty and Dr. Garratt-Reed's family gathered to celebrate his accomplishments.

CMSE activities are guided and supported by four internal committees and one external committee. The Committee on CMSE, Internal Advisory Committee, Space Committee, and Educational Outreach Committee are internal MIT committees that offer guidance to CMSE on research, large equipment purchases, space, safety, and educational matters. The Science and Engineering External Advisory Board offers guidance on ways to enhance collaborations, and it supports major efforts in long-range materials research and engineering.

Michael F. Rubner
Director
TDK Professor of Materials Science and Engineering

More information about the Center for Materials Science and Engineering can be found at http://web.mit.edu/cmse/.