

## 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 was 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 more than 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 180 faculty members in 13 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 seven or more departments. During the first two and a half years of our 2008–2014 MRSEC award, researchers published results in 209 papers and were awarded 18 patents related to their MRSEC research, with 25 more patents pending.

Our SEFs are used by numerous research groups from MIT as well as by outside academic and industrial communities. During the March 2010 to February 2011 period, 1,095 people used our SEFs, including 813 students and postdocs of MIT faculty in 22 academic departments, labs, and centers; 69 students and staff of faculty from 10 outside academic/research institutions; 185 students from MIT lab subjects; and 28 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. During the summer of 2010, 105 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 1,400 people attended workshops and public events in which CMSE participated.

### **Interdisciplinary Research Programs and Scientific Accomplishments**

The MRSEC grant supports three IRGs, two initiative projects, and five seed projects involving 41 principal investigators. Over the past year, CMSE conducted both seed and initiative funding competitions. The results of these funding competitions and the research findings of all FY2011 funded groups are reported below.

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

The objectives of this IRG are to use electrochemistry to accurately determine how thermodynamics, phase stability, and kinetics are modified at the nanoscale, to apply that knowledge to engineer materials with high-energy, high-power storage capabilities, and to 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); D. Nocera (Chemistry); T. Van Voorhis (Chemistry); and C. Thompson (DMSE).

#### **FY2011 IRG-I Results**

IRG-I members have determined that lithium ion transport in olivine-type structured battery materials can be several orders of magnitude faster in nanoparticles than in bulk materials. This has important implications for engineering the rate at which battery materials can be charged or discharged. In a collaborative effort with IRG-II, researchers also found that layer-by-layer assembled multiwall carbon nanotube-based electrodes

exhibit 5 to 10 times higher energy densities than supercapacitor electrodes, and 5 to 10 times higher power than lithium battery electrodes. With further development, this discovery could lead to high-power, high-energy storage microscale energy sources.

IRG-I researchers also synthesized new AuPt bimetallic coreshell nanoparticles with tunable platinum surface coverage. In a PtAu/C battery system, they observed the lowest charging voltage and highest round-trip efficiency of any Li-O<sub>2</sub> cells reported to date. These unique characteristics are related to the ability of the nanoparticles to effectively electrocatalyze both reduction and oxidation reactions: namely, they behave as a bifunctional electrocatalyst. This is important as lithium-air batteries have the potential to exhibit more than a threefold higher energy density than lithium-ion batteries. AuPt alloy nanowires were also synthesized for studies of CO and ethanol oxidation. In this case, nanowires with controlled diameter sizes were fabricated via the surfactant-mediated biomineralization of an M13 phage virus. Encouraging preliminary results indicated that these virus-prepared nanowires exhibit higher ethanol oxidation activity than commercial Pt/C catalysts.

### **IRG-II: Mechanomutable Heteronanomaterials**

This IRG seeks to develop a new class of “mechanomutable heteronanomaterials,” which the group defines 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. 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, IRG-II explores 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); K. Van Vliet (DMSE); and A. Balazs (University of Pittsburgh).

### **FY2011 IRG-II Results**

IRG-II research has made significant progress in modeling, fabricating, and testing a variety of nanoscale heterostructured materials that can undergo substantial changes in mechanical properties with suitable chemical, electrochemical, or mechanical triggers (mechanomutability). For example, nanotube forest arrays fabricated from templated polymer multilayers were found to exhibit more than an order of magnitude change in indentation modulus with a change in solution pH. A variety of modeling and simulation work, including finite element analysis and coarse-grain modeling, provided a nanoscale to microscale understanding of the elements controlling many of the novel experimentally observed mechanical effects.

IRG-II researchers also combined computational simulation and experiments to explore how the shape and size of self-oscillating polymer gels can be used to predictably engineer properties and applications. These studies showed that mechanical stress

can be used to reliably trigger such oscillations: a gel that exists in a non-oscillatory state can be induced to start changing in both color and physical size by application of compressive mechanical stress. This is useful for both sensor applications and models of biological oscillations. This IRG also developed polymer thin film coatings that can undergo reversible and dramatic swelling/deswelling transitions that are triggered with electrochemical pulses and accompanied by significant changes in shear and loss modulus. These novel electrochemically driven discontinuous changes in the swelling and mechanical properties of a surface coating are useful for such applications as controlling adhesion of proteins or cells on surfaces, drug delivery, and flow control in fluidic devices.

### **IRG-III: Multimaterial Multifunctional Nanostructured Fibers**

This IRG explores 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. These fibers, while comprising all of the essential crystalline semiconductor device attributes, are 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. Soljagic, coleader (Physics); J. Joannopoulos (Physics); S. Johnson (Mathematics); and E. Ippen (Electrical Engineering and Computer Science [EECS]).

### ***FY2011 IRG-III Results***

IRG-III researchers continued development of a unique class of multimaterial optical fibers containing integrated electronic devices with nanometer feature sizes. In an exciting new development, this group has fabricated integrated piezoelectric photonic fibers that contain a piezoelectric polymer, conducting electrodes, and insulating claddings. These new piezoelectric fibers can create electrical energy from acoustic vibrations or actively modulate the reflection spectrum of the photonic bandgap fiber. Driven by theoretical work and fundamental processing studies, researchers were able to overcome problems with capillary break-up, introduce crystalline materials, and obtain the piezoelectric polymer in the required ferroelectric beta phase. Piezoelectric fibers with an integrated Fabry-Perot optical cavity were fabricated, and researchers demonstrated that the resonant frequency of the cavity could be controlled through electrical modulation directly applied to the embedded piezoelectric element. The group also demonstrated the ability to create large-area fabrics from these mechanically robust and yet flexible fibers.

Another important development was the establishment of a comprehensive theoretical framework to analyze the lasing action in optically pumped, rotationally excited molecular gases confined in a metallic cavity, which could result in far-infrared and terahertz sources able to operate efficiently at room temperature. Finally, the researchers created a coherent, femtosecond-time-resolved, experimental approach that simultaneously measures dynamic loss and the dynamic index of refraction of nanostructured silicon-based photonic devices.

### **Initiative-I: Engineering Living Cells via Nanomaterials**

This initiative seeks to 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, or therapeutic strategies based on nanomaterial-modified cells), suggest directions for the development of new materials for these applications, and allow explorations of societal concerns relating to the potential toxicity of nanomaterials in vivo.

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

#### ***FY2011 Initiative-I Results***

Initiative-I researchers continued development of cargo-carrying nanoassemblies that can be attached to the surface of living cells without interfering with normal cellular behavior. Important developments include the demonstration that polymer backpacks can be attached to macrophage cells without being internalized and without adversely influencing cellular health and functions and the demonstration that T-cells fitted with surface-attached cargo-bearing nanoparticles exhibit their normal trafficking of proteins in the cell membrane. These results point to the successful integration of functional synthetic nanomaterials with living cells.

### **Initiative-II: New States of Frustrated and Correlated Materials**

This initiative focuses on materials based on two-dimensional triangular and kagomé lattices. The materials developed have attracted much interest and 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 with possible applications in quantum computing. The addition of mobile charge carriers to these systems may lead to unconventional superconductivity and non-Fermi liquid ground states. There is clearly much interesting territory to explore once candidate samples are synthesized. A key 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, co-leader (Chemistry); S. Chu (CMSE); E. Hudson (Physics); and D. Shim (Earth, Atmospheric, and Planetary Sciences).

#### ***FY2011 Initiative-II Results***

Initiative-II researchers continued their explorations of a new state of matter called “quantum spin liquid” by synthesizing single crystal materials with a spin-1/2 kagomé lattice (composed of corner-sharing triangles). Detailed investigations of the material

known as herbertsmithite revealed that the nonmagnetic ground state of this system is not due to chemical disorder but is in fact the result of the intrinsic effects of quantum fluctuations coupled with geometric frustration. This has great implications for the theoretical framework needed for understanding the rich observations in this material. Also, magnetic measurements of single crystal samples revealed a magnetization plateau, thereby providing strong evidence for a spin liquid ground state.

## **FY2011 Seed Research**

### ***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. A working prototype of a nanoparticle transport system with integrated single-particle detection is expected to 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 diagram). Faculty participant and department affiliation: N. Gedik (Physics).

### ***Seed III: Tailoring Optical Properties of Semiconductor Nanomaterials***

This project concentrates on seeking a direct correlation of structural/optical properties of semiconductor nanowires with high-spatial-resolution techniques. 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, both to study fundamental quantum electronics

and to assess the devices' potential as chemical and mass nanosensors. A crucial element of this research is the fabrication of high-quality suspended graphene devices. Multi-terminal 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 graphene nanoribbons will be actuated as tunable high-frequency nanoresonators. In addition, the possibility of passivating the edges of graphene nanoribbons 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 past 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).

#### **Seed and Initiative Funding Competitions**

During the late fall and winter, the center conducted a competition for five new seed projects, soliciting proposals from throughout the MIT community. The primary goals of this seed funding are to (1) support research that has the potential to redefine the direction of an existing IRG or initiative project, (2) lead to the creation of a completely new IRG or initiative project, and (3) foster a newly appreciated opportunity for high scientific discovery or technological impact. Seed funding also serves as an ideal vehicle for recruiting new researchers, particularly junior faculty members, into CMSE research programs. Eleven seed proposals were received by the January 14 deadline, and these proposals were then extensively reviewed by the CMSE director and the Internal Advisory Committee. The winners (all junior faculty members) and their proposal titles are listed below.

Seed I: Alfredo Alexander-Katz (assistant professor, DMSE), Bioinspired Environment-responsive Ligand-coated Nanoparticles

Seed II: Mircea Dincă (assistant professor, Chemistry), Ordered Microporous Electrodes for High-power Sustainable Li-ion Batteries

Seed III: Timothy Lu (assistant professor, EECS), Patterning Multiscale Nanostructures with Synthetic Biology

Seed IV: Yuriy Roman (assistant professor, Chemical Engineering), Atomic Layer Deposition for the Design of Novel Catalytic Materials

Seed V: Evelyn Wang (assistant professor, Mechanical Engineering), Electrical-field Controlled Bio-membranes for Efficient Water Desalination

During this same time period, the center also conducted an Institute-wide initiative competition for two new initiative groups with funding to start in June 2011. Five initiative proposals were received and rigorously reviewed by the CMSE Science

and Engineering External Advisory Board, including a daylong meeting in which all prospective initiative leaders presented their proposed research to the CMSE director and external advisory board. After recommendations from the advisory board, the CMSE director made final funding decisions and announced the two new initiative groups.

Initiative-I: Quantum Optoelectronics and Spintronics with Topological Insulator Nanoscale Devices, Pablo Jarillo-Herrero (assistant professor, Physics), Nuh Gedik (assistant professor, Physics), and Jagadeesh Moodera, PhD (Francis Bitter Magnet Laboratory)

Initiative-II: High Def Nano Materials: New Routes to 3D Hierarchical Nanostructured Materials and Devices, Robert E. Cohen (professor, Chemical Engineering), Michael F. Rubner (professor, DMSE), Mehmet Toner (professor, Harvard-MIT Division of Health Sciences and Technology), and Brian L. Wardle (associate professor, Aeronautics and Astronautics)

### **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 2011, 1,095 different individuals utilized 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 (the Research Experiences for Undergraduates program and the Community College Program) are trained to use equipment in the SEFs to conduct their research. Teachers in the Research Experience for Teachers program spend one morning each week learning about the capabilities and research applications of the equipment in the SEFs. Some of them are also trained to use the instruments for their research projects. 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.

A Physical Electronics VersaProbe II Scanning ESCA Microprobe (XPS) with multiple accessories was purchased in May to serve critical needs of the MIT research community. The current CMSE XPS (circa 1998) located in our Materials Analysis SEF has failings that limit its utility and availability for researchers desiring this important surface analytical technique. The new instrument will offer significant improvement in utility and throughput for XPS users. The current XPS user community includes 37 research groups from nine MIT departments, undergraduates from an MIT undergraduate course, and outside academic researchers from Tufts University, Harvard University, Boston College, and Boston University. The new instrument is expected to be installed and running by the end of 2011.



The 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 the past academic year, 185 undergraduate students used the facilities as part of their laboratory subjects. Lab subjects included courses in DMSE, EECS, Nuclear Science and Engineering, and Earth, Atmospheric, and Planetary Sciences.

SEF staff members offered a number of mini-courses during MIT's Independent Activities Period to train students to operate SEF equipment and apply the latest techniques to their research problems. In January, a total of 96 students and postdoctoral associates attended courses taught by SEF staff.

This year Dr. Scott Speakman was named a fellow of the International Center for Diffraction Data.

### **Launch of a New Shared Experimental Facility**

On September 1, CMSE was notified of the award of a \$1,837,421 NSF American Recovery and Reinvestment Act grant to renovate laboratories on the third floor of Building 13 and create a new, energy-focused shared experimental facility.

The proposed renovation will establish the Nanostructured Materials Growth and Metrology Laboratories (NanoMat Labs), which will be housed within CMSE. A total of 2,900 square feet of wet lab, clean room, and research space will be renovated to establish the new facility. The cross-disciplinary interactions that are at the core of CMSE activities will also be reflected in the operation of the facility, as the NanoMat Labs will be used collaboratively by research groups from materials science and engineering, chemical engineering, electrical engineering and computer science, mechanical engineering, chemistry, and physics. The labs will support the research activities of more than 70 graduate students and postdoctoral fellows.

Much of the work performed in the NanoMat Labs will be directed towards the use of nanostructured materials in energy-related projects, with the major focus on photovoltaic structures, batteries, fuel cells, and high-efficiency solid-state lighting. The research tools housed inside the facility will support several large interdisciplinary programs, including the Eni Solar Frontiers Research Center at MIT, the MIT Solar Revolutions Center, the US Department of Energy-funded Excitonics Energy Frontier Research Center (EFRC) at MIT, the MIT Solid-State Solar-Thermal Energy Conversion EFRC, and MRSEC. The Eni Solar Frontiers Research Center has provided nearly \$1.8M for the purchase of many of the tools to be housed in this new shared facility.

The new facility will operate according to the same business model used in CMSE's other shared experimental facilities. User fees are a source of support for this facility, and fees for instruments housed in the center will be established in the same manner as in the other shared facilities. CMSE has managed shared facilities for more than 40 years and has been highly successful with this model of operation.

## **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, which connects MIT research to industry. These organizations combined have more than 200 member companies.

During this reporting period, MRSEC faculty and/or their group members engaged in at least 85 meetings with representatives from a broad range of different 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 3M, BASF, Bosch, Chevron, Covidien, ExxonMobil, Johnson & Johnson, Nissan, Procter & Gamble, Sanyo Electric Company, and Sharp.

CMSE continues its involvement in one of the showcase MIT materials events, the annual Materials Day at MIT organized by MPC. CMSE now contributes significantly to this symposium's technical program and poster session. One important objective of this event is to connect MIT materials research to managers and researchers from industry and government laboratories. The title of this year's event was "Materials for Sensors." Professor Carl Thompson from MPC provided introductory remarks and an overview of the program. The meeting was attended by nearly 110 registered guests from industry, government laboratories, hospitals, MIT, and other universities, as well as by an additional 78 researchers and students from MIT who joined throughout the day on a walk-in basis. Representatives from more than 70 US and foreign companies attended the event, including employees of 3M, Bosch, Lockheed Martin, Lord Corporation, Raytheon, Saint-Gobain, Schick, and T2Biosystems. The capstone poster event included posters from CMSE students and others from the MIT materials science community. The poster session was judged by a panel of members from MPC's Advisory Board, which includes research managers from industry. This year the session had 82 contributed posters, the largest number ever for this event.

CMSE continued collaboration with the DMSE and the MPC to bring a wide variety of speakers from outside of MIT to meet with faculty and students and deliver lectures to which the entire MIT community was invited. These lectures typically drew audiences of 80–140 people. In fall, Michael Rubner kicked off the series with an overview of CMSE research. Other fall speakers included Susan Trolier-McKinstry (Penn State), Malcom Stocks (Oak Ridge National Laboratory), Kripa Varnasi (MIT), Daryl Chrzan (University of California, Berkeley), and John Rogers (University of Illinois at Urbana-Champaign). Spring speakers included Tim Lodge (University of Minnesota), Simon Billinge (Columbia University), Kimberly Hamad-Schifferli (MIT), Arumugam Manthiram (University of Texas at Austin), and Obed Rabin (University of Maryland).

MRSEC-supported faculty presented an overview of their research in three Industrial Liaison Program-sponsored conferences: the 2010 MIT Research and Development Conference (S. Leeb, Y. Shao-Horn); EmTech India 2011 (D. Novera); and the 2011 MIT

Europe Conference: Innovation in a Networked World: Technology, People, and Places (M. Buehler). These conferences were attended by more than 1,000 representatives from companies including 3M, Emerson, General Electric, Goodyear, LG Electronics, Mazda, Mitsubishi, Nokia, Pfizer, Robert Bosch, Saab, and Siemens.

An important mechanism for knowledge transfer is the creation of new companies and businesses. Currently active CMSE-related companies that were started by MRSEC faculty, students, or postdocs include OmniGuide Inc., LumArray, Luminus Devices Inc., QD Vision, Kateeva, WiTricity Corporation, and Svaya Nanotechnologies. 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. It is estimated that total direct job creation by the most closely CMSE-related companies (OmniGuide, LumArray, Luminus Devices, QD Vision, Kateeva, WiTricity, and Svaya Nanotechnologies) is about 300 jobs and growing.

MIT's Technology Licensing Office is kept aware of new discoveries emanating from CMSE research and helps researchers file patents and issue licenses. Since the start of the current CMSE MRSEC grant, 18 new patents have been issued and 25 new patent applications/provisional patents are pending that are related to MRSEC. In addition, there are currently 18 active industrial, academic, and governmental licenses of CMSE-patented research.

The center's MRSEC-supported faculty enjoy a high level of outside collaboration. During the current MRSEC grant, there have been 10 industrial collaborations, 30 collaborations with outside academic researchers, and 11 collaborations with government laboratories and agencies that were MRSEC-related. In addition, a number of CMSE faculty members have 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.

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.

For the past five years, CMSE has collaborated with Roxbury Community College to make research experiences available to its students. The objective of this dedicated

Research Experiences for Undergraduates program is to engage community college students in current materials research and encourage them to pursue careers in science and engineering. In 2007, the program was expanded to include students from Bunker Hill Community College. Both colleges have significant enrollments of minority students.

## Precollege Education

### *Materials Research Experience for Teachers*

For the past 12 years, CMSE has operated a successful Research Experience for Teachers 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 they can be shared with other educators. Lesson plans written by the teachers are distributed to other science teachers and used in teacher workshops.

Relationships between CMSE and Research Experience for Teachers participants extend beyond the summer program. The teachers bring students to campus and arrange for MRSEC researchers to visit their classrooms.

### **Research experience for teacher participants, 2010.**

Name	School/Subject(s) taught	Research project or lesson plan
Carol Cafasso	Gloucester High School, Gloucester, MA/ chemistry, physical science	tunable photonic gels
Lisa Cody	Kennedy-Longfellow Elementary School, Cambridge, MA/middle school science	reducing global warming by strengthening cement
Scott Hubeny	East Boston High School, Boston, MA/ physics	structural and optical characterization of laser- irradiated silicon
Gift Jaja	Boston Community Leadership Academy, Boston, MA/physics, chemistry	light-scattering measurement of thin film thickness
Kurt Lichtenwald	Gloucester High School, Gloucester, MA/physics, robotics, engineering and technology	physics of energy
Holly Marcus	Somerville High School, Somerville, MA/ physics	batteries and circuits lesson plans
Sarah Page	Boston Community Leadership Academy, Boston, MA/biology, physiology	measuring impact: monitoring water and electricity usage at home

Feedback from recent participants in the Research for Teachers program indicates 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 experience at CMSE is the incorporation of more hands-on lab projects. Program participants often share their units and program 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 ninth time in the summer of 2010. The goal of the program is to deepen teachers content knowledge in areas related to the stated learning standards. It consists of a one-week, hands-on workshop, "Dustbusting by Design," in which 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, 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.



*CMSE RET participant, Lisa Cody, at work in Prof. Krystyn Van Vliet's lab*

MRSEC supports up to five teachers in this program each year. Participants receive a small stipend and professional development points. They are recruited from local school districts, from former applicants to the Research Experience for Teachers program, and through alumni of CMSE's education programs. Four teachers participated in the STEP (one registrant had to withdraw). Three taught physics at public high schools, and the fourth taught high school physics at a local private girls' school. Three of the participants were women, including one African American. The STEP participants completed entrance and exit surveys to give CMSE a sense of how well this workshop met their professional needs. The respondents indicated that the program increased their content knowledge while giving them ideas and confidence to incorporate more applied physics and design projects in their classrooms.

A companion effort to STEP is CMSE's collaboration in the Women's Technology Program 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 Women's Technology Program participants to join the lab portion of STEP to gain hands-on engineering experience. For the past nine years, this has been an extremely successful collaboration. Women's Technology Program alumni report that the motor-building lab is an exciting part of the program. CMSE continued to support the Women's Technology Program by providing the curriculum and supplies and will continue to do so in 2011.

### ***Workshops and Public Events***

MRSEC faculty and students contributed to a variety of programs and events on campus, at local schools, and at other public venues. Professor Leeb presented a talk on his research into materials for lighting to a group of 60 undergraduates visiting MIT from Aristotle University in Greece. For the second consecutive year, Professor Leeb also taught a four-session materials and energy class to 25 high school students who were on the MIT campus to participate in the Research Science Institute. The institute is a well-established national six-week research program for outstanding high school students that is sponsored by the Center for Educational Excellence.

The MIT Educational Studies Program provides opportunities for students to teach classes on campus to middle and high school students from the greater Boston area. CMSE provided supplies and Professor Leeb advised three undergraduates who taught a “reverse engineering” class to 12 students in the spring High School Studies Program. During the class, the high school students deconstructed everyday appliances to understand the underlying science and engineering. The MIT students used the CMSE Van de Graaff generator to teach the high school students about voltage, current, resistance, and static electricity.

Another high school student spent the summer of 2010 working in Professor Leeb’s lab. Christopher Lang from Lincoln Sudbury Regional High School in Sudbury, MA, conducted research on the physics of energy. He worked closely with Research Experience for Teachers program participant Kurt Lichtenwald, and they jointly presented a poster at the MPC poster session at summer’s end. While there is no formal program to place groups of high school students in research labs, CMSE tries to match interested students with research projects whenever possible.

Over the course of the year, CMSE faculty presented demonstrations or gave lectures at local K–12 schools. Professor Angela Belcher kicked off the science fair at Fiske Elementary School in Lexington, MA, with a presentation on materials in nature. The school-wide event was attended by approximately 500 students. In addition, Professor Leeb led a group of 15 local Cub Scouts to conduct energy experiments. He also conducted a strobe photography activity with about 40 Girl Scouts. At Winnbrook Elementary School in Belmont, MA, Professor Leeb taught an activity on sound and materials to a fourth-grade class of 25 students. Finally, he presented demonstrations on motors at the Belmont Science Night, which was attended by 133 students, teachers, and parents, and a table on polar coordinates at the Belmont Math Night, attended by 200 people.

CMSE faculty contribute to public programs sponsored by local museums and organizations. In the fall, Professor Belcher presented several lectures at the Museum of Science, reaching a total of approximately 200 attendees. She also recorded a podcast titled “Energy Saving Technologies,” available through the [museum’s website](#). In addition, CMSE participated in the fifth annual Cambridge Science Festival held in the spring. This nine-day, city-wide public celebration showcases Cambridge as a leader in science, technology, engineering, and math. It features a wide range of science-related activities, including lectures, exhibitions, plays, and concerts. One highlight of the festival is a science carnival incorporating dozens of tabletop demonstrations and

activities. At the carnival, four MIT graduate students and three MIT postdocs presented demonstrations on magnetic fields and superconductivity. This event is typically attended by more than 200 people of all ages.

### ***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 19 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.

During the summer of 2010, 18 students attended with their science teachers. Thirteen of them were girls, and 11 were members of underrepresented minority groups.



*CMSE middle school program participant in the glass blowing lesson*

The program covers a wide variety of topics. Most activities take place during 90-minute periods, and some include multiple sessions. The program included classes on glassblowing, metal casting, electrochemical energy, building simple DC motors, and electric circuitry. Polymer demonstrations, a presentation on the Meissner effect, and a discussion of superconductivity were also included.

In focus group discussions at the end of the program, the students were able to explain the material presented during the week and identify new terms they learned during the program. On exit surveys, participants described the program as a fun way to learn. All of the respondents said they would recommend the program to their friends. Because the students are on campus from 8 am to 3 pm each day, meals are provided by CMSE. The center also provides bus transportation between the schools and the MIT campus.

Each year, families of program participants are invited to the concluding “Shoot-the-Hoop” design competition. Professor Leeb and program staff evaluate and modify activities annually (some activities are modified versions of material used in MIT undergraduate classes). 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. These collaborating partners contribute to the development and implementation of projects.

## **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, four undergraduate students (including two 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, 13 undergraduates (including eight 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 across multiple terms.

### ***Summer Research Internship Program***

In collaboration with MPC, CMSE sponsors the Summer Research Internship Program (through the NSF Research Experiences for Undergraduates 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 179 applications for the summer of 2010, 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 14 students accepted into the summer program included nine women and five men. Four of the 14 were from underrepresented minority groups.

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 Research Experience for Teachers program 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.

The results of the cross-site Research Experiences for Undergraduates program assessment indicated that the CMSE program had a positive impact on students' professional development and their career plans. Participants in the program felt their summer research experience increased their confidence in their ability to contribute to science as well as their presentation and research skills. Also, 89% said that their experience clarified for them which field of study they want to pursue; 95% indicated that the program prepared them for graduate school; 72% reported that they left the program more likely to enroll in a PhD program in science, engineering, or math; and 78% felt they were more likely to pursue graduate study in materials science or engineering.



## 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.

CMSE's Community College Program (CCP) is another targeted Research Experiences for Undergraduates program designed to enhance the diversity of undergraduate participants in MRSEC's research and education programs and to broaden participation among science and engineering professionals. Four students from two local community colleges that enroll significant numbers of minority students (40% at one and 55% at the other) participate in CCP each summer.

Over the six years that the program has been in place, 65% of the participants have been minority students and 48% have been women. Typically, community college students do not have opportunities to gain research experience at their home institutions. By participating in CCP, they learn research and technical lab skills that increase their confidence and prepare them to pursue bachelor's degrees and science and engineering careers. The program also broadens their view of science and engineering. Through its expanded partnership with Bunker Hill Community College, CMSE invites academic classes to tour the SEFs to learn about the instruments in the labs and how they are used for research. To date, Bunker Hill faculty have brought 111 of their students to CMSE. The faculty has indicated that, in addition to learning about how the sophisticated tools in the SEFs support research, the students are introduced to a broader range of science and engineering career options than those with which they are familiar. These tours also provide a chance to talk with the students about possible participation in the CCP.

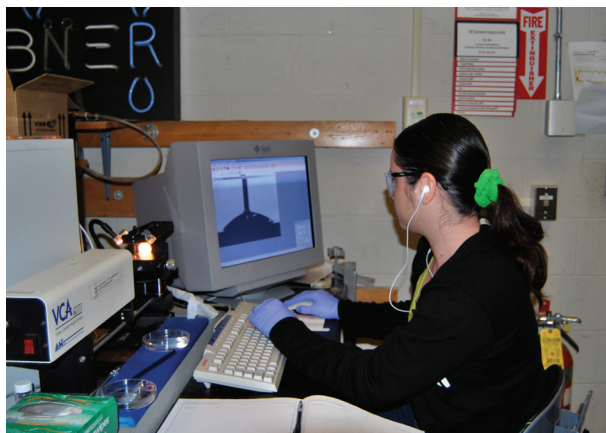
The community college students spent nine weeks during the summer working on CMSE research as part of faculty-led research groups for which the students were awarded stipends. They chose their research projects from several presented by the MRSEC director during a preliminary seminar. Once on campus, the community college students participated in all Research Experiences for Undergraduates program meetings and activities.

During the summer of 2010, two Roxbury Community College students and two Bunker Hill Community College students, including one African American and two women, participated in the program. The students also participated in the MRSEC cross-site assessment. Two of the CCP participants are continuing at community college and expect to transfer to four-year schools in the fall of 2011 to pursue bachelor's degrees. One student is now working for a civil engineering firm. The fourth student transferred to the University of Massachusetts, Amherst, where he is pursuing a bachelor's degree in civil engineering.

Continuing an extension of the partnership with Bunker Hill begun two years ago, MRSEC SEF staff presented demonstrations of how equipment in the Electron Microscopy and X-ray Diffraction SEFs are used in research. During the visits, staff

members explained equipment operation and capability and then demonstrated equipment use so that students could see actual samples. Professor Elizabeth Dunphy of Bunker Hill integrates these visits into her biology classes. In two visits during the past year, 30 community college students visited the labs. MRSEC will continue to offer this opportunity to classes from both community colleges and will consider other opportunities to train community college students to use SEF equipment.

An exciting program in CMSE's education portfolio designed to enhance the research skills and experience of students at Puerto Rican universities is the continuing 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; another UMET student participated in the summer of 2009 and two more in the summer of 2010. This partnership draws students from the Universidad del Este and Universidad del Turabo as well as UMET. Each summer, two positions in the MPC Summer Research Internship Program are dedicated to students from UMET and its affiliated universities. Dr. Juan Arratia, executive director of the Student Research Development Center at UMET, coordinates the recruitment and referral of students. In the summer of 2010, Juan Lozada and Amarilys Rivera Nieves participated in the internship program. Both students also presented posters on their summer research at the 2010 Society for Advancement of Chicanos and Native Americans in Science annual meeting.



*Universidad del Turabo student Amarilys Rivera Nieves participated in the 2010 REU program*

In an effort to recruit Research Experiences for Undergraduates program participants from institutions that have significant numbers of students from underrepresented groups, CMSE directly advertises the program to minority-serving institutions. In the fall, 375 letters with attached recruitment posters were emailed to principal investigators at NSF-funded Centers of Research Excellence in Science and Technology and Historically Black College and University Undergraduate Programs, as well as to recipients of Broadening Participation Research Initiation Grants in Engineering. For the past few years, CMSE has also advertised the program via the Institute for Broadening Participation's online directory of research experiences for undergraduates programs. Finally, the center encourages former minority participants to refer other students at their home institutions to the internship program. Although CMSE has not yet met its goal, this year the targeted recruitment efforts resulted in higher percentages of program applications from women and minority students. Of the 180 applications received for the upcoming 2011 program, 14% were from minority students and 33% were from women, increases of 4% and 6%, respectively.

With regard to K-12 education and expanding the pipeline of a diverse group of future scientists and engineers, CMSE seeks to impact the classroom experience of a large

number of minority students by strengthening the materials content knowledge of their science teachers. For the Research Experience for Teachers program, the center is committed to at least 50% participation by teachers from schools attended by significant numbers of underrepresented students (more than 50%). Five of the seven teachers in the 2010 program were from such school districts in Massachusetts (three from Boston, one from Cambridge, and one from Somerville). Through the Science and Engineering Program for Middle School Students, CMSE directly engages local middle school students. Students for this program are drawn from two Cambridge public schools where approximately 50% of the registered students are from underrepresented minority groups. Consequently, although the number of female and minority program attendees varies from year to year, the program reliably reaches a diverse group of young people. Average participation in this program over the past five years has been 50% female students and 47% minority students. In the summer of 2010, 72% of the participants were girls and 61% were minority students.

### Postdoctoral Mentoring

A total of 27 postdoctoral associates worked on CMSE research during the past year, 17 of whom were paid with MRSEC funds. As part of the center's mentoring plan, the director organized a meeting of all postdoctoral associates working in groups led by MRSEC faculty (whether or not they are directly supported by CMSE). This meeting was held in spring 2010. As a result of that meeting, a committee composed of CMSE postdocs was established with the goal of providing advice to the director on postdoc mentoring opportunities and issues. Shortly thereafter, it was decided that CMSE would organize annual mentoring events by partnering with different MIT academic departments.



*2011 IAP CMSE/DMSE Post-doctoral Mentoring Event*

The first of these events was an Independent Activities Period event held in January, "Is There Life After Being a Materials Post Doc at MIT?" The event, jointly sponsored by CMSE and DMSE, included a panel discussion and a social networking component. It was attended by 25 postdocs and six faculty members. The panel consisted of Professor Belcher, professor Christopher Schuh, and two former MIT postdocs now employed in industry. They shared their career development stories, described how they balance their professional and family lives, and answered questions about topics such as securing

research funding and finding a job search tips. The panel discussion was followed by a social hour to provide time for one-on-one conversation and informal networking. On exit surveys, postdocs who attended indicated that they found this type of event useful and suggested topics of interest for future events. A small group volunteered to serve on a planning committee. CMSE intends to collaborate with other materials-related departments to present similar events each year.

### **Administration, Management, and Research**

Our MRSEC program is administered by a proactive and effective management team that responds quickly to emerging program needs. 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. CMSE currently has a faculty education program leader who marshals our educational outreach plans with our education officer.

To help junior faculty reduce the financial burden of establishing a research program, MRSEC launched the CMSE Junior Faculty SEF Award. CMSE recognizes the financial burden MIT junior faculty face in utilizing large experimental facilities for research needs and has started this new award program to assist these faculty members in accessing the CMSE shared experimental facilities. Contingent on the availability of center discretionary funds (this program is supported by funds distributed to CMSE from technology licensing revenues), CMSE funds five to seven individual awards per year to MIT assistant professors at a level as high as \$5,000 for each award.

Each award will last for one year and can be applied only to user fees in CMSE shared experimental facilities. These awards are restricted to faculty engaged in research activities related to aspects of materials science and engineering as practiced at CMSE. During the fall, one- to two-page research proposals for these awards were solicited from junior faculty throughout the MIT materials community. All of the proposals were reviewed by the center director, and awards were presented based on the strength of the faculty proposal and the financial need justification. The following MIT junior faculty (assistant professors) were award recipients in 2011:

Cullen Buie, DMSE

Tonio Buonassisi, Mechanical Engineering

Paola Cappellaro, Nuclear Science and Engineering

Mircea Dincă, Chemistry

Bradley D. Olsen, Chemical Engineering

Katharina Ribbeck, Biological Engineering

Yuriy Roman, Chemical Engineering

CMSE has continued to support the joint CMSE/DMSE colloquium series initiated in 2005 with the DMSE and expanded in 2007 to include the Materials Processing Center. The DMSE/CMSE/MPC partnership allows the center to pool resources and bring in speakers from outside of MIT. The objectives of the colloquium series are to provide an opportunity 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. A total of 11 lectures will be held this year, with three speakers from MIT, seven speakers from universities around the country, and one speaker from a national lab. Professor Michael Rubner, CMSE director, started the fall series with a talk focusing on the interdisciplinary research activities currently ongoing at CMSE. To promote inter-MRSEC interactions, two of the speakers are part of MRSEC programs at their universities: Timothy Lodge, director, University of Minnesota MRSEC; and Susan Trolier-McKinstry, seed program, Penn State MRSEC.

CMSE also hosts the MIT-wide Facilities Managers Group. This group was formed to better coordinate the synergistic activities of the large materials community at MIT. The CMSE director and one of the CMSE SEF managers, chosen each year by the CMSE director, chair the group, and meeting arrangements are made by CMSE headquarters staff. A meeting is planned for summer 2011 after the launch of the Common Object Representation for Advanced Laboratories (CORAL) facilities lab management program in the CMSE shared experimental facilities. The CORAL software has now been reconfigured for use in the CMSE shared experimental facilities and loaded onto the new server purchased for this purpose. The rollout of this comprehensive lab management system, which includes online user registration, real-time instrument status, and a complete billing module, is now completed in the CMSE Materials Analysis SEF and is in process of being implemented in the CMSE X-ray Diffraction and Electron Microscopy SEFs. The full rollout of CORAL in all SEFs is expected to be complete by late fall 2011.

CMSE activities are guided and supported by three internal committees and one external committee. The Committee on CMSE, Internal Advisory Committee, and Space 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 supports major efforts in long-range materials research and engineering.

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