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). 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 encourage fundamental research and education in the science and engineering of materials for long-range applications that will address the 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 the researchers of 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 research. Our research programs typically support a total of 30 to 40 faculty members from eight or more departments. During the past year alone, our CMSE faculty published 71 papers in which research results were either primarily or partially supported by MRSEC funding or related to our SEFs. About 600 papers have been published over the life of the present MRSEC grant.

Our SEFs are used by numerous research groups from MIT as well as by outside academic and industrial communities. Last year, about 825 people used our SEFs, including students and postdocs of 107 MIT faculty in 27 academic departments, labs, and centers; 87 students and staff of faculty from 14 outside academic/research institutions; and the staff of 11 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, 117 people participated in our various core programs with support from CMSE-funded faculty, graduate students, and postdocs. CMSE MRSEC faculty also devoted more than 300 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 340 people attended workshops and public events in which CMSE took part.

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 eight SEF staff support the program.Administrative staff includes an education officer, facilities and safety coordinator, financial administrator, financial and operations assistant, assistant to the director, assistant director, and director. SEF staff includes one technical associate, four research specialists (one recently hired into our Electron Microscopy SEF), a project technician, a principal research scientist, 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.

CMSE activities are guided and supported by five internal committees and one external committee. The Education Committee, Safety Committee, Space Committee, Internal Advisory Committee, and Committee on CMSE are internal MIT committees that offer guidance to CMSE on educational matters, space, safety, and research. The Science and Engineering External Advisory Board offers guidance on ways to enhance collaborations and support major efforts in long-range materials research and engineering.

In July 2002, CMSE was awarded a $22.2 million grant from NSF through the MRSEC program. This grant covers the funding period from September 1, 2002, through August 31, 2008. In September 2005, we hosted a midgrant site visit from NSF. The visiting panel proclaimed CMSE "one of the premier research programs in the country" and "the world leader in a number of the research areas described in the IRGs." The panel went on to say that "the Center has tremendous impact on the materials research community at MIT and technology development." The panel recommended continued support for CMSE's MRSEC grant through August 2008, the end of the present grant. This past winter we submitted a noncompeting continuation proposal that described our activities during the sixth period of funding of our MRSEC grant.

During 2007, in preparation for our MRSEC renewal competition, CMSE continued an MIT-wide IRG competition to select IRG groups to be included in the 2007 preproposal, submitted to NSF in September 2007. Existing IRGs competed head-on with newly proposed IRGs. During this process, all proposed IRG leaders were encouraged to increase the number of women and minorities in their groups. Ten proposed IRGs were subjected to a rigorous review process that involved internal and external evaluations, including an evaluation by CMSE's Science and Engineering External Advisory Board. After this meeting and further follow-up discussions between the director and the proposed IRG leaders, five new IRGs were chosen and a pre-proposal was submitted to NSF built around this five-IRG center. This pre-proposal included 35 faculty from 11 different MIT departments; 14 of the faculty members were new to CMSE, 11 were junior faculty, eight were women, and two of the women were minorities.

As a result of a very favorable NSF review of this preproposal, CMSE was invited to submit a full proposal, which was built around the same five IRG technical programs

and submitted to NSF in January 2008. Again after very favorable NSF review and feedback, the CMSE director and IRG leaders were invited to attend a "reverse" site visit at NSF on May 21, 2008, to present proposed research for the new grant. The official announcement about our renewal will be made by NSF in September 2008.

Interdisciplinary Research Programs

During the past year, CMSE supported four IRGs and one initiative project involving 31 principal investigators. These are summarized below.

IRG-I: Microphotonic Materials and Structures

Microphotonic materials are rapidly emerging as one of the most promising new platforms for future optical devices and device components. Such materials allow an unprecedented level of control over the confinement and propagation of light, at dimensions that enable the design and eventual integration of a large number and variety of optical micro devices on a single chip. The objectives of this IRG are to explore materials issues and fundamental properties of photonic crystals, to discover physical phenomena associated with photon states that have never been possible before, and to exploit this knowledge with the ultimate aim of the design, fabrication, and characterization of novel microphotonic devices and components.

Participating faculty and departmental affiliations: J.D. Joannopoulos, IRG leader (Physics); E.P. Ippen, L.A. Kolodziejski, and H.I. Smith (Electrical Engineering and Computer Science [EECS]); Y. Fink (Materials Science and Engineering [DMSE]); and K.A. Nelson (Chemistry).

IRG-II: Nanostructured Polymer Assemblies

Polymers and polymer nanocomposites with functional electronic, optical, and biointerface properties are becoming increasingly important in many new technologies that exploit nanoscale-related properties and effects. This IRG seeks to gain a fundamental understanding of the factors that control the way multicomponent, functionally active polymer systems organize at the molecular and nanoscale levels and to use this knowledge to control and significantly enhance the performance of electronic, magnetic, biosensor, and optical devices based on these materials.

Participating faculty and departmental affiliations: A.M. Mayes, IRG leader (DMSE); R.E. Cohen (Chemical Engineering); and P.T. Hammond, C.A. Ross, M.F. Rubner, and E.L. Thomas (DMSE).

IRG-III: Electronic Transport in Mesoscopic Magnetic and Semiconductor Structures

Modern electronics have provided the foundation for the scientific and technological advances of the last few decades but will soon face serious obstacles that may further limit miniaturization and development. Nanoscale elements, with properties dominated by quantum mechanics, are expected to play an important role in overcoming many of these barriers. The focus of this IRG is to explore charge and spin transport in solid-state electronic structures whose building blocks are in the nanometer size regime in order

to understand the fundamental physical principles governing transport through and between these potentially important building blocks of future electronic devices.

Participating faculty and departmental affiliations: M.G. Bawendi, IRG leader (Chemistry); R.C. Ashoori, M.A. Kastner, and L.S. Levitov (Physics); and V. Bulovic and R.J. Ram (EECS).

IRG-IV: Science and Engineering of Solid-state Portable Power Structures

The need for efficient portable power is extremely important in today's society and is becoming critically important to many new technologies that will impact consumer electronics and communication, health monitoring, entertainment, environmental oversight, and national security. This IRG seeks to develop the basic science and engineering of materials for solid-state electrochemical power sources and to use this fundamental knowledge to design devices with energy and power delivery capabilities far superior to those of anything available today. The knowledge gained from fundamental materials studies is expected to have a real impact on practical advances in the battery field.

Participating faculty and departmental affiliations: G. Ceder, IRG leader (DMSE); A.M. Mayes and D.S. Sadoway (DMSE); Y. Shao-Horn (Mechanical Engineering); M.Z. Bazant (Mathematics); and A. Belcher (DMSE and Biological Engineering).

Initiative Project I: Exotic States of Correlated Electrons in Single Crystals

The overall objective of this initiative is to discover and understand the exotic phases that arise in materials with strongly interacting electron systems. Materials of this type can exhibit unusual properties such as superconductivity, anomalously high thermopower, or infinite ground-state degeneracy. Single crystals of the newly discovered superconductive cobaltates will be synthesized and studied with the specialized techniques of neutron and synchrotron X-ray scattering and scanning tunneling microscopy (with atomic resolution).

Participating faculty and departmental affiliations: Y. Lee (Physics) and D. Nocera (Chemistry), initiative coleaders; and S. Chu (CMSE).

Scientific Accomplishments during the Past Year

IRG-I continues to pioneer the development of cylindrical photonic crystal waveguides and microcavities. During the past year, this group played an important national role in establishing key computational tools for photonic crystal researchers. During this time, IRG-I added to its 3D time-domain code support for anisotropic materials, including magneto-optic and magnetic materials and materials with nondispersive complex dielectric functions. The MIT 3D time-domain code is freely available, has been downloaded thousands of times, and is used by researchers around the world. IRG-I researchers have successfully demonstrated large-scale supercollimation in a photonic crystal of silicon rods residing on a thick underlying layer of oxide. This new geometry is important as it limits the problem of coupling with the substrate. Supercollimation is important because it provides a means to direct light without the use of a waveguide

and the inherent problems with coupling and cross talk. This IRG has also introduced a new concept in fiber lasers: dynamic surface-emitting fiber lasers. In contrast to conventional fiber lasers where light originates only from fiber ends, these new fiber lasers can emit radiation radially from any predetermined position along the fiber. This new technology opens up exciting opportunities for enhanced capabilities in medical imaging, vapor detection, photodynamic therapies, and fabric displays.

IRG-II has established new processing techniques for creating nanodot arrays of magnetic materials. Using block copolymers as templates in conjunction with topographic features, this group has demonstrated that highly ordered arrays of magnetic nanodots can be created with either patterned anti-reflective coatings or a sparse template of posts with dimensions commensurate with the size of the block copolymer domains. Magnetic measurements indicate that these arrays are excellent candidates for patterned magnetic recording devices. In the multilayer area, IRG-II researchers have created a functionally active thin film coating that can be loaded with multiple drugs that release in a controlled manner. Most importantly, since the multilayer coating is actually a nanoporous Bragg stack similar to that found in hummingbird wings, the color of the coating changes dramatically as drugs are loaded and unloaded. Hence, these new coatings have a built-in self-monitoring capability. As a result of fundamental studies carried out by IRG-II researchers, five different companies are now funding efforts to develop multilayer coatings for anti-fogging, anti-reflection, and structural color applications.

IRG-III research has revealed that charge transport in an array of PbSe quantum dots is very different from that observed in CdSe dots. In the PbSe case, charge transport was found to be the result of hole-majority carriers that are thermally released from acceptor states. This important observation means that an n-type partner will be needed to create efficient light-emitting devices from this material. This new discovery debunks current literature suggesting that p-type partners are preferred. Measurements of this quantum dot system also revealed a particular trap state on the surface of the PbSe dot surface: a possible route to tuning charge transport by passivating these trap states has been identified. This work opens the door to the fabrication of higher performance PbSe quantum dot–based photodetectors and photovoltaic devices. IRG-III has also demonstrated a novel approach to overcoming the difficult challenge of "wiring" single nanoparticles in electro-optical devices. Using a layered organic electrode geometry, researchers in this group were able to observe directly both the electroluminescence and photoluminescence signals from the same individual dots in a device.

IRG-IV researchers have used a genetically engineered M13 virus as a scaffold for templating the growth and assembly of nanoscale amorphous iron phosphate. These virus-generated nanoparticles appear to be promising for use as the positive electrode material of a rechargeable battery. To date, electrochemical analysis indicates that close to 85% of the theoretical capacity of iron phosphate can be realized from the nanoscale version of this material. Working batteries were successfully assembled and tested. A virus-based approach to synthesizing new nanoscale battery materials is important as the replication process of a virus provides a means to easily and cheaply mass produce such materials. IRG-IV's research also shed new light on the phase transformation

dynamics of $LiFePO_4$ electrode materials. This work has resulted in a fundamental understanding of the lithiation patterns previously observed during battery recharging.

Members of the initiative project made an important breakthrough in their investigation of the fundamental physics of kagomé lattice systems. Utilizing our unique crystal growth facility, they have developed a hydrothermal crystal growth method that yields appreciably-sized single crystalline samples of the S=1/2 kagomé lattice antiferromagnet $ZnCu_3(OH)_6Cl_2$. Crystals as large as 2 mm have been grown. Refinement of the growth technique and preliminary thermodynamic measurements are ongoing.

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 past year, 825 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 (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 included the following:

- The Institute-wide working group of facility managers, established by the MIT vice president for research and chaired by the CMSE director and SEF manager, had two meetings this past year. The main focus of these meetings was further refinement of the shared facilities section of our recently launched collaborative (with the Materials Processing Center [MPC] and DMSE) website Materials@MIT. This section of the site provides a central equipment reference, easily updated by local personnel, that leads to more extensive information on each facility's own web pages. It is now possible for researchers to identify quickly, and at one site, all shared experimental equipment at MIT that is important for materials science and engineering research. Other topics discussed included unmet equipment needs at MIT, how each facility handles outside users, and the establishment of a common booking and billing system for all facilities at MIT.
- This past year, we have continued to operate a JEOL 2010FEG TEM instrument jointly owned with the Institute for Soldier Nanotechnologies (ISN). As a result of CMSE's extensive experience with running shared facilities, it was decided that the full management of this microscope (including training and billing) would be handled solely by CMSE.

- During the past year, 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. About 150 undergraduate students used the facilities as part of their laboratory subjects, and each staff member offered at least one mini-course during MIT's Independent Activities Period (IAP) in January 2008 to train students to operate SEF equipment and apply the latest techniques to their research problems.
- Also, in order to more broadly engage the MIT community, our SEF staff organized for the first time an outside speaker seminar that focused on data analysis and interpretation. The seminar, given by Dr. Kateryna Artyushkova from the Department of Chemistry at the University of New Mexico, addressed the use of multivariate statistical analysis in extracting information from disparate data sets. In the future, our SEF staff plan to sponsor a yearly seminar in which experts from around the country will present topics of interest to the MIT community. In addition, a number of vendor-presented seminars and/or demonstrations were organized or sponsored. Companies involved in these events included Panalytical, Oxford Instruments, the Carl Zeiss Instrument Division, and Olympus Industrial.
- New capabilities were added to our SEFs through the purchase and installation of a field-emission source scanning Auger microprobe and a cathode luminescence attachment for one of our transmission electron microscopes. The new Auger is capable of an ultimate spatial resolution of 7 nm and is the only instrument of its kind in the New England area. The cathode luminescence attachment for our JEOL 2011 TEM allows the acquisition of cathodoluminescence signals at very high spatial resolution. Providing ultra-high spatial-resolution probing of electron energy levels in solids, this system, which will be unique in an academic setting in North America, will be invaluable to research in semiconductor nanostructures as well as other areas.

Collaboration, 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 MPC and the Industrial Liaison Program (ILP), which connects MIT research to industry. These organizations combined have more than 200 member companies. Our faculty engaged in 90 ILP-organized meetings with representatives from a broad range of domestic and foreign companies, including 69 visits from industrial representatives, eight faculty visits to different firms, and 13 briefings to company executives. MRSEC-supported faculty presented an overview of their research in three ILP-sponsored conferences: the 2007 MIT Research and Development Conference (Darrell Irvine, Nocera, Ram); the MIT Europe Conference in Brussels, Belgium (Sadoway); and the 2007 MIT in Japan Conference (Krystyn Van Vliet, Ceder). In total, these conferences were attended by more than 500 representatives from more than 100 different US and foreign companies, including 3M, Apple, Denso Corporation, Ford, Hitachi, Mitsui, Raytheon,

Sanyo Electric, Sun Microsystems, and Toyota. In addition, professors Hammond and Cohen presented MRSEC-supported work at a daylong symposium honoring the 25-year collaborative relationship between MIT's Department of Chemical Engineering and the Bayer Corporation.

In this year's MPC-hosted "Materials Day at MIT," four CMSE-supported faculty, professors Ross, Hammond, Francesco Stellacci, and Cohen, presented their latest research results in a symposium titled "Thin Films and Coatings: Designed and Processed to Enhance Function and Performance." Also, a new CMSE-originated industrial collaboration with Essilor Corporation was highlighted during the meeting, which was attended by about 130 people, many from industry, government labs, and other universities. Companies represented included 3M, Analog Devices, Bayer, Boeing, Bose Corporation, Corning Energizer, Essilor, FujiFilm/Mitsui, General Electric, Hitachi, Lockheed Martin, Michelin, Nikon, Pall Corporation, Procter and Gamble, Raytheon, Samsung, Shell Oil, and Toshiba, to name a few. The capstone poster event included posters from CMSE students and others from the MIT materials science community; two students from CMSE-supported research groups won prizes for best poster: Joe Walish (Thomas group) and Ayse Asatekin (Mayes/Rubner group). The poster session was judged by a panel of 15 judges from MIT's ILP and from Saint-Gobain, Altran Solutions, Lockheed Martin Advanced Technology Center, Ventura Group, Harmonic, and UltraClad. Given continuing involvement that CMSE has had in organizing the technical programs for this event, starting in 2008, CMSE will jointly sponsor the symposium.

CMSE, DMSE, and MPC jointly sponsored the Materials Seminar Series this past year (see list in the Education and Human Resources section). In order to foster inter-MRSEC interactions, seminar speakers included Professor Shu Yang of the University of Pennsylvania MRSEC and Craig Hawker, director of the University of California, Santa Barbara, MRSEC. In addition, a special half-day seminar organized by DMSE was devoted to the important issue of energy. This seminar, titled "Frontiers of Materials Science: Materials Challenges, Solutions, and Developments in the Energy Problem," included a big picture overview of MIT's current Institute-wide energy initiative by Ernest J. Moniz (MIT Physics Department and director of the MIT Energy Initiative) and technical presentations by MIT professors Ceder and Yet-Ming Chiang on the role of computational materials science in energy and leading-edge battery technology. Professor Sanjeev Mukerjee (Northeastern University) also presented a talk titled "Finally Unplugged: Revolution in Energy Conversion." This symposium was attended by approximately 250 students, researchers, collaborators, and alumni from the MIT community and the general public.

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 new 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 this site is a database of all materials-related shared equipment at MIT, including all CMSE user equipment.

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 our faculty, students, or postdocs include Little Optics (bought by Nomadics Inc.), OmniGuide Inc., LumArray, Luminus Devices Inc., and QD Vision (Clarendon Photonics, another company that we have reported on in recent years, is now defunct.). These various companies were founded to develop novel devices and components based on discoveries made within our MRSEC program and funded, in many cases, exclusively through NSF. OmniGuide is expanding rapidly, and numerous surgical operations that use the company's technology are performed each week in the United States. Total direct job creation by these companies is about 275 jobs to date. Additionally, Nanosys and Quantum Dot Corporation (bought by Invitrogen) are companies whose technology platform is based in part on CMSE-supported fundamental research.

During the 2007–2008 MRSEC funding period, 21 new patents were issued and 32 new patent applications/provisional patents related to MRSEC are pending. In addition, there are currently 24 active industrial licenses of CMSE-patented research. During this funding period our faculty reported MRSEC-related collaborations with 16 different industrial organizations, 37 outside academic institutions, and 16 government laboratories and agencies. In addition, a number of our 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

Over the past six years, we have 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 Bunker Hill Community College (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 300 hours to tutoring students, making presentations

to students and teachers, supervising high school students doing research in their labs, and hosting groups of students visiting CMSE laboratories. The 68 students and parents and 100 teachers who participated in these activities are affiliated with approximately 10 different organizations external to MIT. In addition, Professor Nocera, along with cartoonist Odd Todd and Robert Krulwich of ABC News, developed a web-based video production on the chemistry of global warming titled "It's All About Carbon" (http://www.npr.org/news/specials/climate/video/). The video is being used in classrooms and will be distributed by National Geographic.

For the past three years, CMSE has collaborated with Roxbury Community College, 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. BHCC also has a significant enrollment of minority students (40%). The MRSEC funding for this program has been augmented by direct MIT support. As a special incentive for the program, during 2006 and 2007, the vice president for research and the deans of science and engineering provided the funds to support three of the community college students.

Precollege Education

Materials Research Experience for Teachers

For the past nine 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 2007, five new teachers worked on research and four returning teachers (one of whom was funded by the Siemens Foundation) 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.

- "Biomimicry: A Study of Adaptations and Their Practical Use for Humans" (Keagan Belanger, Nashua High School North, Nashua, NH)
- "Thin-Film Nanomagnets and Magneto Devices: An Elective Course for Secondary School" and a companion, "Thin-Film Nanomagnets and Magneto Devices: Hands-On Activities" (Mary Espanol, the Winsor School, Boston, MA)

- "Nanoscintillators: Crystal Clear Images from Faint Radiation Sources" (a presentation for high school science teachers) (Andrew Klein, Boston Latin School, Boston, MA)
- "Characterization of a Magnetic Induction Flashlight" (Sean Müller, Merrimack High School, Merrimack, NH)

Mr. Klein made a presentation based on his MRET research on development of scintillating nanomaterials to 12 members of the Boston Latin School science faculty, and provided colleagues with an introduction to nanoscience and X-ray fluorescence. Mr. Müller's unit was used in a freshman seminar at MIT and with his students at Merrimack High School. In addition, the unit was modified for use by middle school students.

One of the ways in which the MRET program impacts students is that participants identify opportunities on campus for their students. Some bring their students to MIT for tours and lab activities. For example, Sean Müller brings five to eight students to Professor Steven Leeb's lab each year to work on electronics projects. He and a colleague from Merrimack High School also use the high-speed photography unit developed during their summers at CMSE to teach an "envisioning science" class at the Rivier Challenge after-school program at Rivier College in New Hampshire. They have taught a class of approximately 32 tenth-grade students for each of the past six years. Another MRET participant, Mary Espanol, arranged to have one of her students, Gillian Chase, join her in Professor Ross' lab during the summer of 2007 to develop the lab activities associated with her unit on thin-film nanomagnets and magneto devices. Gillian had an opportunity to see firsthand the research Ms. Espanol did during the summer of 2006 and to use some of the equipment in the SEFs. She helped write the classroom unit and create the poster presented at the poster session. She will also serve as a lab assistant when Ms. Espanol uses the unit with her classes at the Winsor School.

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. Teachers tell us that as a result of their experience at MIT, they try to develop more collaborative labs rather than having every student do the same exercise. The program participants often share their units and MRET experience with fellow teachers at their schools and at regional and national meetings. Two of last summer's participants, Mary Espanol and Sean Müller, conducted workshops with colleagues attending the National Science Teachers Association annual conference this past March. Hands-on workshops on magnetic induction flashlights and thin-film nanomagnets were included in the "Explorations @MIT" segment of the conference. Sixteen teachers and six high school students participated in these two workshops led by Ms. Espanol and Mr. Müller.

Science Teacher Enrichment Program and Women's Technology Program

CMSE offered its Science Teacher Enrichment Program (STEP) for the sixth time in the summer of 2007. 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 that meet the machine's 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). EECS administers this four-week summer residential program for 40 high school girls from across the country, during which the participants take classes in math, computer science, and engineering. The program is designed to address a gender imbalance in the field of engineering by increasing 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 six years, this has turned out to be 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 2007 and will continue to do so in 2008.

Workshops and Public Events

This past April, CMSE participated in the second annual Cambridge Science Festival. CMSE's contribution to the "Science Carnival" portion of the festival included posters and table demonstrations of polymers led by CMSE graduate student Daniel Alcazar. It is estimated that nearly 200 attendees visited the CMSE tables.

In addition, the center sponsored two workshops for third- and fourth-grade students. In December 2007, Professor Leeb presented an "Introduction to Semiconductors" program to a group of 10 third-grade Cub Scouts. The program consisted of explanations of diodes and radios, followed by a hands-on activity in which the boys made crystal radios. The second workshop took place at "Science Night" at the Winn Brook School in Belmont in February. Professor Leeb led 137 third- and fourth-grade students in making small DC motors.

Science and Engineering Program for Middle School Students

The center has operated a science and engineering program for seventh- and eighth-grade students from Cambridge Public Schools for the past 15 summers and continued to offer it in 2007. 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 2007 middle school program took place during the weeks of August 6–10 and August 13–17. 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 2007 program included glassblowing, polymer demonstrations, electric circuitry, DC motor construction, and a 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 presented by MIT faculty, staff, graduate students, and undergraduates. To present this program, 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. Many 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 grant year, seven students (including four women) participated in the program with support from CMSE. In addition to the students paid by MRSEC, seven undergraduates, two of whom are women, worked on CMSE research. These students either were supported by other funds or received academic credit. Some of them 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 2007, which were reviewed by a committee consisting of the CMSE director and staff from both centers. Participants are chosen from this pool on the basis of academic performance, interest statements, and faculty references. The 16 students accepted into the program for the summer of 2007 included seven women and nine men, two of whom are from underrepresented minority groups.

The students are paid stipends and work full time for nine weeks. Most of them live in a dormitory on campus. Weekly meetings are 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 complete the program by producing posters that report on their summer's research. The resulting poster session is held during the final week and is open to the entire MIT community. It includes posters produced by participants in CMSE's MRET and community college programs as well and serves 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 being done 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

RCC student Brandon Tench, far right, with his family and Professor Bertley, far left, at the poster session.

In an attempt to build a relationship with community colleges in the Boston area that enroll a higher percentage of underserved students, we launched a new program in 2005 in collaboration with Dr. Ray Turner, executive dean of academic affairs at RCC. The initial phase of this program established a formal research experience program for RCC students at MIT and was formally extended to BHCC in 2007. This program began in summer 2005 with five RCC students; continued in 2006 with four new RCC students, a new student from Massachusetts Bay Community College, and two returning RCC students; and continued again in 2007 with four RCC students and two BHCC students. Also, in 2007, to further enhance student recruitment into this program, we established relationships with Professor Frederic Bertley from RCC and Professor Karen Atkinson from BHCC. The program is continuing in 2008 with two new students from RCC and two new students and one returning student from BHCC. Overall objectives are to engage community college students in current materials research and to encourage and enthuse them to pursue four-year degrees and careers in science and engineering.

CMSE is particularly interested in working with community college students, as they often do not have research opportunities at their own institutions. In 2007, participants included three African American and two Hispanic students, four of whom are women. Students were chosen to participate in this program by faculty at their home institutions.

The group spent 10 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 REU meetings and activities. In addition, two separate meetings of these students with the MRSEC director and staff were devoted to addressing their questions about research and obtaining feedback on the program. In August 2007, participants in this program presented posters on their research at the REU/MRET poster session. The RCC students' posters were displayed outside the library at RCC during the academic year.

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.

In an effort to develop potential partnerships with 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. The return on this effort has been limited. We sent recruiting material to these institutions again for the 2007 program. Clearly we will have to develop deeper discussions with faculty and administrators at the identified institutions to significantly impact our pool of applicants. Efforts will therefore be made to establish direct connections to faculty at some of these institutions.

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 led by professors Eric Klopfer and Kim Vandiver, and the center has contributed to collaborative Institute-wide education efforts such as the National Science Teachers Association's "Explorations@MIT" this past March.

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. CMSE provides earmarked funds to support assistantships for graduate students from underrepresented minority groups. During the past grant year, four minority research assistants were supported directly by CMSE. This targeted funding is supplemental to a faculty member's existing CMSE funds, providing an incentive to include minority students in his or her research group.

Colloquia

CMSE is continuing its joint colloquium series with DMSE and MPC. This partnership allows us to pool resources and bring in speakers from outside MIT. Objectives of the

colloquium series are to provide 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. This joint series also strives to promote inter-MRSEC knowledge transfer.

A complete list of speakers for the fall 2007 and spring 2008 series follows.

- Fall 2007: Sergio Lozano-Perez (University of Oxford), Sara Majetich (Carnegie Mellon University), Federico Capasso (Harvard University), Craig Hawker (MRSEC director, University of California, Santa Barbara), Joerg Lahann (University of Michigan)
- Spring 2008: Elsie Morgan (Boston University), Naomi Halas (Rice University), Roger Hanlon (Marine Biological Lab, Woods Hole, MA), Juan de Pablo (University of Wisconsin), John Cumings (University of Maryland), David Srolovitz (Yeshiva University)

In addition, professors Moniz, Ceder, and Chiang spoke at the special half-day seminar organized by DMSE, titled "Frontiers of Materials Science: Materials Challenges, Solutions, and Developments in the Energy Problem," described earlier in the Collaboration, Outreach, and Knowledge Transfer section.

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