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 110 faculty members in 12 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. 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, shared experimental facilities (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 to redefine 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 35 to 40 faculty members from seven or more departments.

Our SEFs are used by numerous research groups from MIT as well as by outside academic and industrial communities. Last year, over 775 people used our SEFs, including students and postdocs of 93 MIT faculty in 22 academic departments, labs, and centers; students and staff of 62 faculty from 19 outside academic/research institutions; and the staff of 16 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, over 140 people participated in our various programs with support from CMSE-funded faculty, graduate students, and postdocs.

Our industrial interactions/knowledge transfer activities have resulted in the establishment of new products, applied funding, a new MIT center (the Microphotonics Center) and numerous start-up companies. For example, a number of small companies have emerged from or are based in part on CMSE research, including Clarendon Photonics (now defunct), Little Optics (now part of Nomadics), Cumulus Photonics (now defunct), OmniGuide Communications, American Superconductor, Quantum Dot

Corporation (now part of Invitrogen), LumArray, Luminus Devices, Inc., QD Vision, Nanosys Inc., GelMed and Gel Sciences. All of our activities are highly integrated and often combine elements of research with educational and industrial outreach.

Administration, Management, and Research

Our MRSEC program is administered by a proactive and effective management team capable of responding quickly to the emerging needs of the program. Currently seven administrative and eight SEF staff support the program. The administrative staff includes an education officer, facilities and safety coordinator, financial administrator, financial and operations assistant, assistant to the director, assistant director, and director. The SEF staff includes one technical associate, four research specialists (one slot currently open due to retirement of a staff member), a project technician, a principle 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's activities are guided and supported by four internal and two external committees. The Education Committee, Safety Committee, Space Committee, and Internal Advisory Committee are internal MIT committees offering guidance to CMSE on educational matters, space, safety, and research. The Science and Engineering External Advisory Board (SEEAB) and the Committee on CMSE offer 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 mid-grant 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 also went on to say "the Center has tremendous impact on the materials research community at MIT and technology development." They recommended continued support for CMSE's MRSEC grant through August of 2008, the end of the present grant. This past winter we submitted a non-competing continuation proposal that described our activities during the fifth period of funding of our MRSEC grant.

In addition, during the past year CMSE has begun preparations for its 2007–2008 NSF six-year center grant renewal competition. To put together a proposal with the strongest possible research and educational outreach programs, CMSE began preparations for this NSF competition nearly a year in advance with an IRG competition open to all MIT faculty. In order to broadly canvas the MIT community, the CMSE director held two town meetings to explain the NSF MRSEC program, our present renewal process, and the formation and research goals of an IRG. Research groups were then asked to submit five-page papers describing their research and group members. This process yielded 10 papers; all of these groups were then invited to submit longer papers giving more detail on proposed research and faculty group members. Both MIT and outside reviewers

provided peer reviews on each submission. In January 2007 we convened the CMSE SEEAB to review each IRG proposal. The leaders of each proposed IRG were asked to present a summary of their proposed research goals as well as information about the group's faculty members. All of the information from these reviewers as well as internal reviewers was gathered and recommendations for new IRGs were made to the director. The decision on these five new IRGs was announced in the spring of 2007.

During the summer of 2007, CMSE will prepare a pre-proposal, which will be due at NSF in September of 2007. After NSF review and feedback during the fall of 2007, a full renewal proposal will be presented to the NSF in January of 2008. In the spring of 2008, the CMSE director and IRG leaders will attend a "reverse" site visit at the NSF to present proposed research for the new grant. If all is successful, the new grant is expected to be awarded in September of 2008.

In addition, one ongoing issue at MIT as a whole is security. Over the past several years, CMSE has implemented a card access system for several critical Building 13 lab doors, as our general funds have permitted; however, there were 107 lab doors left to be fitted with card readers. Starting in October 2006, with generous funding from John DiFava, director of Security and Campus Police Services, CMSE embarked on a $213,000 project to install card readers on these 107 lab doors. The project took approximately four months to complete and greatly enhanced security for the people and property located in Building 13.

Interdisciplinary Research Programs

During the past year, CMSE supported four IRGs, one initiative, and five seed projects involving 32 principal investigators. These are summarized below.

Seed and initiative funding plays a critical role in the vitality of MRSEC. The primary goals are to support research that has the potential to redefine the direction of an existing IRG, create a new IRG, or provide an opportunity to move quickly into new research areas.

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 objective of this IRG is 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: John Joannopoulos, IRG leader (Physics); Erich Ippen, Leslie Kolodziejski, and Henry Smith (Electrical Engineering and Computer Science [EECS]); Yoel Fink (Materials Science and Engineering [MSE]); and Keith Adam 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: Ann Mayes, IRG leader (MSE); Robert Cohen (Chemical Engineering); and Paula Hammond, Caroline Ross, Michael Rubner, and Edwin Thomas (MSE).

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: Moungi Bawendi, IRG leader (Chemistry); Raymond Ashoori, Marc Kastner, and Leonid Levitov (Physics); and Vladimir Bulovic and Rajeev 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: Gebrand Ceder, IRG leader (MSE); Anne Mayes, and Donald Sadoway (MSE); Yang Shao-Horn (Mechanical Engineering); Martin Bazant (Mathematics); and Angela Belcher (MSE and Biological Engineering).

Initiative Project I: Chemically Responsive Organic Opto-electronics

The objective of this initiative is to design reproducible, high-performance organic-based transistors and sensors capable of amplified responses to chemical targets. To

accomplish this, the group is developing new methods for the deposition of novel active and passive (protective coatings) molecules and polymers. Chemical specificity in the sensory responses is accomplished by designing materials with specific electronic structures, nanoscopic superstructures, and integration receptors. Particular emphasis is placed on receptors of biological origin, as a result of their exquisite selectivity.

Participating faculty and departmental affiliations: Tim Swager, initiative leader, (Chemistry); Klavs Jensen (Chemical Engineering); and Robert Silbey (Chemistry).

This initiative has been phased out.

Initiative Project II: 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 super conductive 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: Young S. Lee (Physics) and

Daniel Nocera (Chemistry), initiative coleaders; Fangchen Chou (collaborator); and Shaoyan Chu (CMSE).

Seed Projects

The five CMSE-sponsored seed projects and their participating faculty are:

- Regular Nanofluidic-PEM Membrane as a Model System for Studying Ion Transport in Charged Membrane, Jongyoon Han (EECS)
- Modeling and Design of Three-dimensional Nano-acoustic Devices and Phononic Crystals, Steven Johnson (Mathematics)
- Electron Transport Studies in Single-walled Carbon Nanotubules, Jing Kong (EECS)
- The Thermodynamic Costs of Electron-Transfer: Diabatic Marcus Free Energy From First-Principles Molecular Dynamics, Nicola Marzari (MSE)
- Engineering Nanoscale Polymer Films as Tunable Mechanical Substrata, Krystyn Van Vliet (MSE)

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 demonstrated a new topological approach to optical detection utilizing fiber webs constructed from photonic band-gap fibers. This approach overcomes fundamental limitations associated with conventional detection systems by enabling access to optical information at unprecedented volume

and length scales. Optical fibers that can generate electrical signals in response to heat have also been developed. The new fibers enable the development of fabrics for measuring spatially resolved temperature information on large areas with high spatial resolution and low cost. This IRG further demonstrated, for the first time, a supercollimation effect in a photonic crystal that propagates over macroscopic distances. This exciting result paves the way for a novel approach to optical waveguiding, without the need for waveguides and their inherent problems with coupling and cross talk.

In IRG-II, magnetic nanostructures comprised of a single row of block-copolymer templated nanospheres and nano-ellipsiods were fabricated. Such structures provide a means to tune the magnetic anisotropy of templated magnetic dots by choice of aspect ratio and orientation. Members of this IRG also developed new water-based processing techniques that make it possible to assemble multilayered thin film coatings from inorganic nanoparticles such as SiO_2 and TiO_2. Transparent thin film coatings with anti-reflection and self-cleaning properties were demonstrated as well as patterned water harvesting coatings that were inspired by a tiny beetle found in the Namib desert.

IRG-III research has revealed a possible pathway to significantly improving the performance of nanocrystal-based electronic devices. Using "nanodumbells" comprised of a nanorod of CdSe with a nanocrystal of CdTe fused on each end, this group has found that shallow electronic traps can limit device performance. Overcoating such heterostructures with a thin layer of a higher-band gap semiconductor such as ZnS should eliminate this problem, thereby making them ideal for photovoltaic or photodetection applications. Two major advances were also made in the nanocrystal light emitting device (LED) area. First, it was demonstrated that white-light emitting devices with good efficiency could be fabricated from hybrid semiconductor nanocrystal/organic molecule multilayered LEDs. Second, significant progress was made in fabricating "all-inorganic" nanocrystal LEDs. By replacing organic transport layers with layers of inorganic materials like NiO, ZnS and ZnO, they demonstrated light emitting devices that could operate at high brightness and unprecedented current densities of 3.2 A/cm^2. Thus, the group has moved closer to achieving the levels of current densities required for demonstrating electrically driven lasing in nanocrystal-based devices.

IRG-IV members have made a significant breakthrough in the development of a safe, environmentally friendly, high-energy density/high rate capability cathode material suitable for lithium battery use. Guided by theoretical computations, members of this group have experimentally demonstrated that a modified crystal of $Li_xNi_{0.5}Mn_{0.5}O_2$ exhibits significantly enhanced rate performance. This new material is currently optioned for license by two companies and represents the culmination of several years of basic science research on electrode materials funded by the MRSEC program. This group also made important progress toward the biological synthesis of a new generation of very high charge/discharge rate nanoscale electrode materials. The growth of these materials was templated by a virus, an approach that allows for controlled stoichiometry of inorganic materials grown or nucleated on the virus coat.

Initiative Project II members performed detailed thermodynamic and neutron-scattering measurements on their recently synthesized S=1/2 Kagomé material. Results suggest

that an unusual spin-liquid state with essentially gapless excitations is realized in this Kagomé lattice system.

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. A team of highly motivated professionals staffs these facilities. During this past year, over 775 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 this past year include the following:

- The Institute-wide working group of facility managers, established by the MIT vice president of research and associate provost and chaired by the CMSE director and SEF manager, had two meetings this past year. A main topic for discussion was disaster preparedness in order to help protect the enormous investment in sophisticated equipment in user facilities at MIT. To facilitate this discussion, a planning group sponsored by the MIT Department of Facilities and the Environmental Health and Safety Office met with the group and introduced its work, describing methods to evaluate the risk and impact of various natural and man-made disasters. This activity was carried out through a project conducted under the federal Disaster Resistant Universities program. Two members of the planning group subsequently met with the entire staff of the SEFs, raising the same issues. The purpose of this discussion was to bring the importance of planning for this sort of eventuality to the forefront of people's minds, and to provide a basis for estimating the costs and benefits of any additional mitigation efforts that might be considered.
- A second major area of work for this group has been the establishment of a central web location for users to find information on user facilities at MIT. Part of the Materials@MIT web site launched by CMSE/Department of Materials Science and Engineering (MSE)/Materials Processing Center (MPC) in October 2006, this site provides a central reference, easily updated by local personnel, which leads to more extensive information on each facility's own web pages. The listing of the CMSE SEF equipment has been totally revised and updated as part of the launch of this new web site.

- This past year, we have collaborated with the Institute of Soldier Nanotechnologies (ISN) to increase the capability of both centers in the area of electron microscopy. We have put into operation a shared JEOL 2010FEG TEM instrument, which was donated to MIT's ISN by the vendor. CMSE supervises the operation of this instrument and both centers share in expenses.
- Also during the past year, to facilitate the training of industry researchers, in collaboration with PANalytical, Inc., our X-ray SEF staff organized a three-day workshop on using advanced X-ray diffraction data analysis programs. Instructors included PANalytical personnel as well as Dr. Scott Speakman (CMSE SEFs) and Dr. Andrew Payzant from Oak Ridge National Laboratory.
- During this funding period, new capabilities were also added to our SEFs through the purchase of a multi-purpose polycrystalline X-ray diffractometer, an inductively coupled plasma optical emission spectrograph and a field-emission scanning Auger microprobe. This latter instrument provides a unique capability for the New England area academic community and beyond.

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 the MPC and the Industrial Liaison Program (ILP), which connects MIT research to industry. These organizations combined have more than 200 member companies. This past year for example, ILP arranged some 104 meetings between our MRSEC-supported faculty and representatives from a broad range of different domestic and foreign companies. Presentations made by CMSE faculty at MPC and ILP-sponsored conferences reached more than 580 individual representatives from companies such as 3M, Boeing, Ciba Specialty Chemicals, Gillette/Proctor & Gamble, Honeywell, Northrop Grumman, Pall Corporation, Apple, Xerox, DENSO Corporation, Ford, Hitachi, Mitsui, Raytheon, Sanyo Electric, Sun Microsystems, and Toyota.

In order to enhance our knowledge transfer and outreach capabilities, we have launched a new MIT-wide materials website and completely revamped our CMSE MRSEC website. In the former case, a collaborative effort involving the MPC and MSE resulted in the October 2006 launch of a 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 new CMSE MRSEC website 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. Since its launch in July 2006, the site has been viewed by non-MIT visitors over 4,500 times per month, on average.

In October 2006, the MPC/ILP-sponsored "Materials Day at MIT" outreach symposium featured a program entitled "Materials: Science to Systems—How We Made the Future, and What's Next?" This full-day symposium included presentations by professors Michael Rubner and Edwin Thomas on the theme of "Balancing Education, Research, and Technology." At the end of the technical program, a poster session/competition and social was held that included poster presentations from both MRSEC students and post-doctoral associates and group members from the wider MIT materials research community. MRSEC-supported students contributed seven posters to the event. The poster competition was judged by representatives from Analog Devices, Norton, Clarion, Applied Materials, Lockheed Martin, ADE Technologies, and General Motors. Three prizes were awarded to students in recognition of their excellent poster presentations, including to two MRSEC-supported students—Fabien Sorin ("Multimaterials Integrated Fibers"), advised by professor Yoel Fink, and Daeyeon Lee ("All-Nanoparticle Thin Film Coatings: A Versatile Means to Create All-in-One Coatings"), coadvised by professors Robert Cohen and Michael Rubner. This event was attended by 81 representatives from a total of 64 companies. The various participants had an opportunity to interact with a full complement of MRSEC faculty, students, and post-doctoral associates during the technical program, at a sponsored lunch event, and during the poster session. Also in attendance were about 100 members of the MIT community including faculty, graduate, and undergraduate students.

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 post-docs 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 several surgical operations that use their technology are performed each week in the United States. Total direct job creation by these companies is about 210 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 2006–2007 MRSEC funding period, 13 new patents were issued and eight new patent applications/provisional patents have been submitted that are related to the MRSEC. In addition, there are currently 13 active industrial licenses of CMSE-patented research. During this funding period our faculty reported MRSEC-related collaborations with nine different industrial organizations, 37 outside academic institutions, and 16 government laboratories and agencies.

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 working 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 comprised of personnel from MIT who are actively involved in educational outreach efforts. 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 year they devoted about 931 hours to tutoring students, making presentations at schools, to youth groups, and at teacher meetings, or hosting groups of students visiting MIT laboratories. The 697 students and parents and 221 teachers who participated in these efforts are affiliated with 20 different organizations external to MIT.

With the help of supplemental MRSEC funds in 2005, CMSE launched a new collaboration with Roxbury Community College (RCC), a two-year college in the local area. This was the first step in building a relationship with community colleges in the Boston area that enroll a higher percentage of underserved students. The primary goal of this new program is to encourage a significant number of community college undergraduates to pursue careers in science and engineering. For the third year, CMSE collaborated with RCC to make research experiences available to community college students. MIT has made a financial commitment to this program. The vice president for research and associate provost, the dean of science, and the dean of engineering each supported an RCC student this past summer. They have provided the funds to support three students in the summer of 2007 as well.

CMSE is particularly interested in working with community college students, as they often do not have opportunities to be involved in research at their own institutions. Participants in 2006 consisted of six RCC students and one student from Mass Bay Community College. They included five African-American and two Hispanic students, two of whom were women. Two of these students participated in the 2005 program and returned for a second summer. Participants were chosen by RCC faculty on the basis of their interest, academic preparation, and faculty referral.

The president of RCC, Dr. Terrence Gomes, spent the afternoon of the 2006 poster session at MIT. Before speaking with the students and viewing their posters, he met with Professor Rubner, CMSE assisant director Susan Dalton, Professor Donald Sadoway, and Professor Claude Canizares, vice president for research and associate provost at MIT, to discuss continued collaboration between CMSE and RCC on this program. He strongly endorsed the program. In 2007, we will be broadening participation in the program by including two Bunker Hill Community College (BHCC) students. The BHCC campus is located 2.5 miles from MIT, where approximately forty percent of the students are members of underrepresented minority groups.

Pre-college Education

Materials Research Experience for Teachers

For the past eight 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, 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 2006 five new teachers worked on research and five returning teachers worked on creating classroom materials, and during the summer of 2007, nine teachers will be participating in this program, five working on research and four creating classroom materials.

Science Teacher Enrichment Program and Women's Technology Program

CMSE will offer 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 entitled "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 final day of the program 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 five years, this has turned out to be an extremely successful collaboration. WTP alumni report that the motor-building lab was the most exciting part of the program. CMSE continued to support WTP by providing the curriculum and supplies for this part of their program in 2007.

Science Teacher Workshops

CMSE offers workshops that address specific content enrichment needs to groups of science teachers. These are developed in consultation with the teachers, particularly with former participants in the MRET program and STEP.

Three different FIRST LEGO League (FLL) teams have visited CMSE labs in the fall of 2006. The theme for this year's competition is nanotechnology. Professor Belcher's research group is working with about 40 students from local school systems on their projects. Teams are required to explore an application of nanotechnology and either design an improvement for the existing nanotechnology or choose a potential application that faces a challenge and solve it. They must present their research and build a robot to accomplish a given set of missions. Twenty students, five parents, and a teacher, representing two FLL teams from Milford, New Hampshire, visited Professor Belcher's lab in October 2006. The students ranged in age from seven to twelve years old. Professor Belcher began the day with an introductory discussion of nanotechnology, focusing on how biology and life work at the nanoscale. This was followed by demonstrations of how the group uses atomic force microscopy and transmission electron microscopy to image objects at the nanoscale. Dr. Tony Garratt-Reed demonstrated the use of CMSE's scanning electron microscope for this research. The Belcher group members also showed the students how to electrospin virus fibers and how they use bacteria to replicate and amplify viruses. A similar agenda was presented to a third FLL team consisting of seven 6th- and 7th-grade students and their teacher from Lincoln, Massachusetts, in November.

The CMSE education programs leader consistently converts exciting research projects into educational projects he uses in his seminar for MIT freshmen, as well as for K–12 students. In a freshman seminar on the physics of energy that he coteaches, students design and build go-carts, magnetic-induction flashlights (based on the unit developed by an MRET teacher with Professor Leeb), and environment-sensing robots. As reported last year, in November 2005 Professor Leeb conducted a workshop with teachers from the Cambridge Rindge and Latin High School on designing and building similar robots. This workshop resulted in a strong collaboration with physics teacher Margaret Hart. Two of her Applied Physics students worked with Professor Leeb and an MIT undergraduate during the spring term to design and construct a robot outfitted with light sensors that would follow a marked course. The students entered their robot in the TechBoston Robotics Olympics held in May 2006 and won first prize in the "Smart Cars" category. In the fall of 2006, another four of Ms. Hart's students designed and built projects with the help of Professor Leeb. Two students built robots to which they added new features they have designed. A third student used a similar micro circuit board in her design of a steering mechanism for a hovercraft. The final student built an amplifier. This project is not directly related to the original robot, but, because of the collaboration that has been established, Ms. Hart and the student called on Professor Leeb for advice and technical information, and to borrow tools not available at the high school.

During the past year, former MRET teacher Julie O'Loughlin brought a fellow teacher and 38 eighth-grade students to CMSE for a workshop on battery materials, which is described below. Another teacher, Julie Kong, brought her AP chemistry class of 11 students to Professor Shao-Horn's lab and the Electron Microscopy SEF to show them the research she worked on during the summer. While they were on campus, the group also attended a special lecture on energy at the MIT Museum. Teachers Sean Müller and Michael Cirelli of Merrimack High School in New Hampshire bring five to eight students to Professor Leeb's lab each January to work on electronics projects.

These two teachers 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 five years. Furthermore, Mr. Müller arranged to have one of his students participate in research at CMSE over the summer. Desiree Amato, currently a senior at Merrimack High School, worked in Professor Leeb's lab this past summer. She contributed a poster describing her research to the REU/RET poster session in August. It is now on display at her high school, and Desiree is scheduled to share her MIT experience with Mr. Müller's chemistry classes later this year.

High School Student Workshops

As a result of the summers she spent at CMSE as an RET participant, middle school science teacher Julie O'Loughlin has arranged field trips to CMSE for her eighth-grade classes for the past two years. In April of 2006, she and a colleague brought 38 students from Breed Middle School in Lynn, Massachusetts to CMSE for a half-day workshop on battery materials. Two graduate students from Professor Shao-Horn's research group helped design and present this program. They began the day by explaining battery chemistry to the students and leading a discussion on the need for improved batteries. As users of cell phones and hand-held electronic games, the students grasped this quickly. This led to an explanation of the graduate students' research into new battery materials. To illustrate the impact of using different materials, the graduate students were joined by the staff of all of the SEFs to help the students make simple batteries and then explore how the substitution of different metals and different solutions affect the voltage output. This portion of the program was followed by tours of the SEFs, where the staff and graduate students demonstrated how the instruments are used by researchers to learn about the structure and properties of different potential battery materials. The group concluded their field trip with a short visit to the MIT Museum.

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 fifteen summers and will continue 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. Because the students are on campus from 8 am–3 pm each day, meals are provided to participants. CMSE also provides bus transportation between the schools and MIT.

The 2006 middle school program took place during the weeks of August 7–11 and August 14–18. Twenty-two students from the Morse and Peabody Schools attended with their science teachers. The group included 13 boys and nine girls. Eleven of these students are members of underrepresented minority groups. As the teachers know their students personally, they are responsible, with the assistance of other school staff, for selecting the participants. Program activities are designed and presented by MIT faculty, staff, graduate students, and undergraduates.

The program covers a wide variety of topics. Most activities take place during 90-minute periods, and some include multiple sessions. The 2006 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 the families of the program participants are invited. The activities offered are evaluated and modified each year by Professor Leeb and the program staff. The team of faculty, staff, and students who lead activities varies from year to year. To present this program, CMSE has developed collaborative relationships with MIT's Edgerton Center, the MIT Museum, and the departments of Physics, EECS, and DMSE, which contribute to the development and implementation of projects. Many of the 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. During the past grant year, nine students (including five women) participated in the program with support from CMSE. In addition to the students paid by MRSEC, six undergraduates, three of whom were women, worked on CMSE research. These students were either were supported by other funds or received academic credit.

Summer Research Internship Program

In collaboration with MPC, CMSE sponsors a Summer Research Internship Program (through the NSF Research Experiences for Undergraduates [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 receive approximately 120 applications each year, which are 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 10 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 also includes posters produced by participants in CMSE's MRET and community college programs as well and serves the dual purpose of serving 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

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 Roxbury Community College (RCC). The initial phase of this program established a formal research experience program for RCC students at MIT and was formally extended to Bunker Hill Community College in (BHCC) 2007. This program began in the summer of 2005 with five RCC students, continued in 2006 with four new RCC students, a new student from Mass Bay Community College and two returning RCC students and has continued again in 2007 with four RCC students and two BHCC students. Also, in 2007, in order to further enhance student recruitment into this program, we have established an ongoing relationship with Professor Frederic Bertley from RCC and Professor Karen Atkinson, from BHCC. The overall objectives are to engage community college students in current materials research and to encourage and enthuse them to pursue advanced degrees and careers in science and engineering.

The CCP students spend 10 weeks during the summer working on CMSE research as part of a faculty-led research group, similar to our summer internship program. They attend all of our REU meetings and activities as well. Students are chosen by community college faculty on the basis of their interest, academic preparation, and faculty recommendations. Similar to the summer internship program, the students select research projects after attending a symposium to learn about the different projects offered, and are paid a stipend. At the end of the summer, participants will present posters on their research at the REU/MRET poster session. CMSE will work with the community colleges to track these students once they complete the program.

A special feature of this program is that an RCC faculty member has joined a CMSE research group as an MRET participant for the summer. In this capacity, he is furthering his own professional development and, at the same time, is available on campus to mentor and interact with his students.

It should be noted that a CMSE-supported faculty member, Professor Donald Sadoway, has had an informal relationship with RCC for a number of years. For six years, working with Dr. Ray Turner, Professor Sadoway has placed RCC students in CMSE/MIT research groups during the summer and, in some cases, on a part-time basis during the academic year. By all accounts, this has been a very successful collaboration. CMSE seeks to leverage this success by building a more formal and far-reaching program.

REU Outreach to Underrepresented Minorities

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 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 the 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. CMSE sponsored a FAST program at the MIT Museum in January of 2007 in which CMSE researchers presented a program of talks, posters, and demonstrations titled "It's a Material World." We have established strong working relationships and collaborations with other administrative units at MIT, including MPC and various departments in the School of Science and the School of Engineering. CMSE has participated in discussions of the recently formed Committee on MIT K–12 Educational Outreach led by professors Eric Klopfer and Kim Vandiver.

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

Colloquia

CMSE is continuing its joint colloquium series with MSE. This partnership allows us 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. This joint series also promotes inter-MRSEC knowledge transfer.

A complete list of speakers for the fall 2006 and spring 2007 series follows.

Fall 2006:
Julia Kornfield (Caltech), Ainissa Ramirez (Yale University), Gerard Wong (University of Illinois), Vincent Pigot (University College, London), Rachel Goldman (University of Michigan), Miguel Salmeron (Lawrence Berkeley National Laboratory)

Spring 2007:
John Cahn (University of Washington), Darrin Pochan (University of Delaware), Michael Graetzel (École Polytechnique Fédérale de Lausanne, Switzerland), Shu Yang (University of Pennsylvania), Mauro Ferrari (University of Texas at Houston), Mark Asta (University of California at Davis)

Michael F. Rubner
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TDK Professor of Materials Science and Engineering
MacVicar Faculty Fellow

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