Center for Materials Science and Engineering

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

CMSE promotes and facilitates interdisciplinary research and education in the science and engineering of materials. MIT has an exceptionally strong and broad effort in materials science and engineering involving more than 180 faculty members in 13 different departments in the School of Engineering and the School of Science. CMSE brings this diverse materials community together by encouraging collaborative research and innovative educational outreach programs, and by providing state-of-the-art shared experimental facilities (SEFs). The mission of CMSE is to enable—through research, educational outreach, and knowledge transfer—the development and understanding of new materials, structures, and theories that can impact the current and future needs of society. The complexities of such research require input from industry and the expertise of many faculty working collaboratively. To accomplish this mission, CMSE enables collaborative interdisciplinary research among MIT faculty and researchers from other universities, industry, and government laboratories.

CMSE promotes collaborative research through several mechanisms: interdisciplinary research groups (IRGs), seed and initiative projects, SEFs, and outreach programs. CMSE uses seed and initiative funds to support research that has the potential of redefining the direction of an existing IRG or leading to the creation of a completely new IRG. Seed funding provides CMSE with the flexibility necessary to initiate high-risk, transformative research. Our research programs typically support approximately 30 to 40 faculty members from 10 or more departments. During the first three and a half years of our 2008–2014 MRSEC award, researchers published results in 298 papers and were awarded 23 patents related to their research, with 37 more patents pending.

Our SEFs are used by numerous research groups from MIT as well as by outside academic and industrial communities. During the March 2011 to February 2012 period, 1,108 people used our SEFs, including 804 students and postdocs of MIT faculty in 22 academic departments, labs, and centers; 85 students and staff members of faculty from 12 outside academic/research institutions; 202 students from MIT lab subjects; and 17 staff of senior-level industrial managers.

Our educational outreach programs encompass a broad range of activities and age levels, with participation from K–12 students and teachers, and undergraduates from other institutions. During the summer of 2011, 122 people participated in our various

core programs with support from CMSE-funded faculty, graduate students, and postdocs. CMSE MRSEC faculty also devoted many hours to tutoring students, making presentations to students and teachers, supervising high school students in their labs, and hosting groups of students visiting CMSE labs. More than 1,500 people attended workshops and public events in which CMSE took part.

Interdisciplinary Research Programs and Scientific Accomplishments

The MRSEC grant supports three IRGs, two initiative projects, and six seed projects involving 35 principal investigators. Over the past year, CMSE conducted both seed and initiative funding competitions. The results of these funding competitions and the research findings of all groups funded in FY2012 are reported below.

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

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

Faculty participants and department affiliations: G. Ceder, co-leader (Materials Science and Engineering [DMSE]); Y. Shao-Horn, co-leader (Mechanical Engineering); A. Belcher (DMSE and Biological Engineering); K. Hamad-Schifferli (Mechanical Engineering and Biological Engineering); D. Nocera (Chemistry); T. Van Voorhis (Chemistry); and C. Thompson (DMSE).

FY2012 IRG-I Results

IRG-I members have used aligned carbon nanofibers to demonstrate, for the first time, the advantage in gravimetric energy of lithium-oxygen (Li-O_2) batteries relative to Li-ion batteries utilizing $LiCoO_2$ for the positive electrode. By normalizing the performance to the weight of the discharged electrode, an approximately fourfold energy enhancement was achieved relative to $LiCoO_2$. This suggests that electrode structure design is a key consideration for approaching the full potential of Li-O_2 batteries. The use of carbon nanofiber electrodes allowed for clear observation of Li_2O_2 formation and dissolution during discharge and charge as revealed by ex-situ scanning electron microscopy and transmission electron microscopy studies. Such studies are providing a fundamental

understanding of factors currently limiting practical applications of Li-O_2 batteries. In the materials arena, virus templated MnO_X electrode materials for Li-O_2 batteries were synthesized and found to exhibit better capacity and a lower charging potential than previous reports at two times higher current density. This further reinforces previous observations that biotemplated materials can offer great advantages over materials created by conventional approaches. In related work, computational investigations into the electronic conductivity of Li_2O_2 suggest that this material might not be as insulating as previously assumed, provided that the formation of carriers can be achieved.

IRG-II: Mechanomutable Heteronanomaterials

This IRG seeks to develop a new class of "mechanomutable heteronanomaterials," which are defined as possessing spatially localized and controlled nanoscale units of different types of materials that change their mechanical properties reversibly in response to an external stimulus. The use of heteronanostructures provides many exciting possibilities for mechanomutable materials design that have not yet been realized, in particular high-spatial-resolution interactions with nanoscale objects and unique and amplified mechanical robustness. For this reason, IRG-II explores the possibility of utilizing these materials as high-throughput, high-spatial-sensitivity tunable sensors (e.g., for cells, proteins, localized impacts, and pressure in liquids).

Faculty participants and department affiliations: R. Cohen, co-leader (Chemical Engineering); C. Ortiz, co-leader (DMSE); M. Boyce (Mechanical Engineering); M. Buehler (Civil and Environmental Engineering); P. Hammond (Chemical Engineering); K. Van Vliet (DMSE); and A. Balazs (University of Pittsburgh).

FY2012 IRG-II Results

IRG-II researchers have demonstrated that surface-confined nanotube arrays based on polyelectrolyte multilayers exhibit "geometrically controlled mechanomutability" including stimuli responsive frictional forces. This means that the friction coefficient μ can be altered by both the solution pH (material stimulus) and the nanoscale geometry. Such a system is a viable candidate for designing coatings with switchable frictional behavior for drug delivery applications, microfluidic devices, cell culture substrates, and sensors. Computational results provided direct theoretical evidence that microgeometry can be used to amplify and systematically tune mutability. In a new direction, this group has designed and fabricated mechanomutable materials where the internal interfaces reversibly morph to switch from straight to undulating topologies and hence alter the mechanical wave propagation and other functional properties of the composite. IRG-II researchers have also demonstrated for the first time that mechanical load can be used to trigger the chemical reactions that drive the oscillations of self-oscillating polymer gels. It was found that upon application of a critical mechanical compressive stress, the self-oscillations can be revived after damping, visually analogous to the resuscitation of a beating heart. This is the first demonstration of mechanically triggered chemical reactions in a gel and it validates the computational predictions of such chemomechanics by the group. It was also found that disks of these chemomechanically active gels oscillate in color when spaced further apart than a diffusion distance, or they can act as communicating pressure sensors that transmit a signal away from a mechanically loaded site.

IRG-III: Multimaterial Multifunctional Nano-Structured Fibers

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

Faculty participants and department affiliations: Y. Fink, co-leader (DMSE); M. Soljacic, co-leader (Physics); J. Joannopoulos (Physics); S. Johnson (Mathematics); E. Ippen (Electrical Engineering and Computer Science [EECS]); A. Abouraddy (University of Central Florida); and P. Anikeeva (DMSE).

FY2012 IRG-III Results

IRG-III researchers have fabricated an axially invariant, cylindrical photonic bandgap fiber cavity filled with a microfluidic gain medium plug and encircled with an array of electrically contacted and independently addressable liquid crystal (LC) microchannels embedded in the fiber cladding. Using this new construct, they have demonstrated a zero angular momentum laser with purely radial emission. The LC channels modulate the polarized wavefront emanating from the fiber core, leading to a laser with a dynamically controlled intensity distribution spanning the full azimuthal angular range. This new capability, implemented monolithically within a single fiber, presents opportunities ranging from flexible multidirectional displays to minimally invasive directed light delivery systems for medical applications. In an exciting new development, this IRG has developed new methodologies for creating macroscopic lengths of nanowires from thermally drawn fibers composed of multiple material components. These nanowires can be obtained in high-density, well-ordered, globally oriented arrays, making them ideally suited for a wide range of applications in nanoelectronics, energy harvesting, photonic devices, sensing, and interfacing electronics with live cells.

Initiative-I: High Def Nanomaterials: New Routes to 3D Hierarchical Nanostructured Materials and Devices

HD nanomaterials refer to a new class of 3D bulk material elements that can be tailored at the sub-nanometer scale by combining solution-based layer-by-layer (LBL) processing and related techniques (Cohen-Rubner) with the bulk 3D nanoporous carbon scaffolds recently developed and demonstrated as microfluidic elements (Toner-Wardle). Although the applications for this work are manifold, this initiative focuses on developing a fundamental understanding of LBL assembly onto the 3D nanoporous elements, extending the recent space-constrained LBL of Cohen-Rubner to smaller spaces (accessible via aqueous routes) approaching single-nanometer dimensions while simultaneously extending it from planar facing channels to 3D bulk nanoscale features (i.e., for an equivalent volume of channel). In essence, the LBL assembly process will

now occur on 3D surfaces with 5–20 times smaller constraints and more than 2,000% higher surface areas. Biofunctionalized nanoelectromechanical systems (BioNEMS) devices for bioparticle isolation will directly benefit from the surface modification provided by LBL, as it will allow a myriad of new functionalities for the devices to be targeted, moving away from simply functionalizing to truly tailoring and enabling new types of bioparticle manipulation. For example, a targeted device effort will seek to demonstrate LBL-enabled bioparticle capture and manipulation focusing on the HIV virus, approximately 100 nm in size. This capability is currently inaccessible by state-of-the-art nano/microelectromechanical systems platforms. Success in such a device will lead to much broader investigations of nanoparticle-based information about disease processes in the body in future work, including investigations of before-untargeted information packets in fluids (e.g., blood contains nanometer-scale exosomes in small quantities that could be used to track disease evolution and treatment effectiveness). This initiative's work on LBL assembly into bulk nanoporous elements will impact numerous other fields such as filtration, titration, and nanostructured anodes/cathodes.

The ability to tailor interfaces has led to many of the technological advances in materials in recent decades across all domains and is especially relevant when considering nanoscale effects. Biomedical research has particularly benefited from advances in surface chemistry and surface manipulation, enabling a large number of applications from controllable release/adsorption of proteins to affinity chromatography. Layer-by-layer deposition has emerged as a facile and flexible route towards layered molecular assembly, unlocking great potential particularly on films and surfaces. Extending LBL techniques to bulk materials with controlled nanoscale morphology is largely an unexplored area, and it is pursued here via a new route based on microfluidics for achieving 3D LBL assembly via solution processing into nanoporous scaffolds.

Faculty participants and department affiliations: B. Wardle (Aeronautics and Astronautics), R. Cohen (Chemical Engineering), M. Rubner (DMSE), and M. Toner (Health Sciences and Technology).

FY2012 Initiative-I Results

Initiative-I has focused on the important fundamental issue of sequentially adsorbing polymer chains onto the surfaces of carbon nanotubes contained in highly confined nanoforest arrays. Early results suggest that suitable control over solution conditions and the polymer assembly process makes it possible to either just coat the outside surface of the nanotube forests with a conformal coating or have the coating penetrate deep inside the entire forest. Both cases represent opportunities for constructing advanced lab-on-a-chip microfluidic devices with the ability to capture and detect biological entities such as viral particles.

Initiative-II: Quantum Optoelectronics and Spintronics with Topological Insulator Nanoscale Devices

The aim of this initiative is the development of topological insulator (TI) materials suitable for electronic, magnetic, and optical devices. TIs represent a novel paradigm in condensed matter physics, where materials are classified according to the topological order of their band structure. TI devices are expected to allow the investigation of a variety of new quantum phases and to open a broad range of spin-based functionalities. The studies carried out as part of this initiative are focused on the development of TI devices fabricated from thin films and the development of sensitive techniques for spin mapping of TI materials.

The ideal TI would be an insulator in the bulk and support electronic transport only through its topological surface states. At present, TI materials such as Bi_2Se_3 are plagued by a finite carrier density in the bulk. The presence of these carriers limits the applicability of TI devices and hinders the study of surface effects. Growth of TI thin films in high vacuum conditions is a promising approach to addressing these problems. It is also a particularly useful strategy for device fabrication since it offers fine control over geometry and composition and allows the growth of heterostructures.

Faculty participants and department affiliations: P. Jarillo-Herrero (Physics), N. Gedik (Physics), and J. Moodera (Francis Bitter Magnet Laboratory).

FY2012 Initiative-II Results

Initiative-II research focuses on an exciting new class of materials called topological insulators (TIs). Devices based on TIs are expected to allow the investigation of a variety of new quantum phases and to open a broad range of spin-based functionalities. Using a growth procedure developed for the synthesis of low-bulk-density thin films of Bi_2Se_3 on Si substrates, field-effect devices were fabricated and examined. Due to their low bulk density, the devices exhibit remarkable conductance modulation, up to a 500% on/off ratio, and a crossover of the Hall coefficient to positive values. This research proved that it is possible to separate the topological surface state channels from the bulk by modulating the gate voltage of the device.

FY2012 Seed Research

Seed-I: Bioinspired Environment-Responsive Ligand-Coated Nanoparticles

Research Goals

This project seeks to understand, from a theoretical standpoint, how synthetic soluble nanoparticles can fuse reversibly (or irreversibly) with a cellular membrane and behave as membrane proteins. This effort was inspired by work on ligand-protected gold nanoparticles that has shown that such nanoparticles translocate across the lipid bilayer and insert themselves into cells (*Nature Materials*, 2008, Vol. 7, No. 7, pp. 588–595).

Research Accomplishments

A tractable model to study how these nanoparticles interact with bilayers has been explored. This model incorporates the hydrophobicity of the ligand backbones, the mixed character of the ligand shell composed of hydrophobic and hydrophilic ligands, and the charges on the hydrophilic ligands and the bilayer. Two scenarios have been dealt with: nanoparticles that can rearrange their shells globally in response to an inhomogeneous environment (i.e., bilayer with a hydrophobic core approximately 3 nm in thickness and two hydrophilic surfaces) and nanoparticles that can reconfigure their shell only locally, meaning their ligands are fixed at their anchoring point.

Faculty participant and department affiliation: A. Alexander-Katz (DMSE).

Seed-II: Ordered Microporous Electrodes for High-Power Sustainable Li-ion Batteries

Research Goals

This seed project aims to build novel organic electrodes for Li^+ batteries from redox-active covalent organic frameworks (COFs). Owing to their innate porosity, which should allow efficient Li^+ intercalation, COFs are expected to exhibit improved power density relative to other organic electrodes, thereby providing a sustainable alternative to current battery electrodes.

Research Accomplishments

Organic electrodes are a sustainable alternative to current Li^+-ion technology because they can be derived from biomass, making them cheap, renewable, and clean. Their design draws from organic synthetic chemistry, which allows for fine control over the materials' form and function. Preliminary reports indicate that their theoretical capacities and discharge potentials are competitive with household lithium-ion batteries, yet their rate performances are poor. This shortcoming is attributed to densely packed polymeric architectures, which lead to inefficient Li^+ intercalation during cycling. The proposed materials have well-ordered structures that should promote fast Li^+ transport.

Faculty participant and department affiliation: M. Dinca (Chemistry).

Seed-III: Engineering and Patterning Multiscale Nanostructures with Synthetic Biology

Research Goals

Amyloids are aggregates of proteins or peptides with a cross-beta structure and fibrillar morphology that assemble via a rate-limiting nucleation step followed by fibril extension. Self-assembly of amyloid nanowires is based on amino-acid interactions between individual subunits that are programmable via the underlying genetic code. This project aims to engineer curli fibers, which are surface-expressed functional amyloids found in *Escherichia coli*, and explore how genetic changes to the curli subunit, CsgA, affect its functional, chemical, and mechanical properties. Individual curli fibrils are approximately 3–4 nm in diameter, can grow to many microns in length, and can laterally associate to form larger bundles.

Research Accomplishments

A prime effort has been to characterize the mechanical properties of bacterially synthesized amyloids with a particular emphasis on measuring the Young's modulus of curli fibers and integrating bacterial curli fibers into macromaterials. Indirect and direct methods to characterize the Young's modulus have been explored. The indirect method is based on monitoring the shape of fibers observed on a mica surface on atomic force microscopy (AFM). Based on thermal fluctuations, the Young's modulus is calculated from the deviation of the shape of the fiber from the segment that connects its free ends. The AFM images of the fibers were elaborated for height information by using ImageJ and Matlab.

Faculty participant and department affiliation: T. Lu (EECS).

Seed-IV: Atomic Layer Deposition for the Design of Novel Catalytic Materials

Research Goals

The objective of this seed project is to implement synthesis strategies using atomic layer deposition (ALD) for the production of advanced catalytic materials with molecular control over the composition and/or placement of single-component and multicomponent active sites. A collaboration with Cambridge Nanotech, a startup based on Harvard professor Roy Gordon's ALD techniques was established to perform the depositions.

Research Accomplishments

In the first year, two parallel approaches to the synthesis of novel materials were investigated. Track 1 consisted of using ALD to post-synthetically functionalize defect sites in zeolites with water-tolerant Lewis acids. Zeolites containing Lewis acid sites (e.g., Sn-Beta) require long crystallization times (approximately 40 days). An alternative strategy consisted of synthesizing a zeolite without the Lewis acidic heteroatom (for 8–12 days) and then adding the heteroatom post-synthetically. Heteroatom framework incorporation is usually low using liquid-phase processes as a result of unwanted hydrolysis reactions of the metal salts; thus, ALD is ideally suited to avoid such side reactions.

Faculty participant and department affiliation: Y. Roman (Chemical Engineering).

Seed-V: Electrical-field Controlled Bio-membranes for Efficient Water Desalination

Research Goals

Lipid bilayers, which are the basis for cell membranes, undergo a remarkable transformation under electric fields where small nanopores can be opened and closed. If this process can be properly controlled, artificial membranes for filtration or desalination could be developed. The goal of this study is to model this complex behavior and eventually demonstrate filtration control of an artificial lipid biomembrane.

Research Accomplishments

The focus of the current work has been to understand the fundamental molecular components and interactions of the lipid film structure. According to the thermodynamics of pore formation, interfacial and surface energy components largely dictate the ability to electroporate a lipid bilayer. Lipid monolayers have been deposited onto mica substrates in order to study these effects experimentally. The same system has also been studied in molecular dynamics simulations in order to corroborate experimental results. Some of the main accomplishments during this seed period are as follows: (1) a method of evaluating the surface energy of lipid films, (2) the development of a model to determine the dispersive surface energy of a lipid film, and (3) the identification of defects (and their cause) within monolayer films and their effects on wetting.

Faculty participant and department affiliation: E. Wang (Mechanical Engineering).

Multi-faculty Seed-VI: Soft-Matter Hierarchical Assemblies for Directed Energy Flows

Research Goals

This project seeks to develop antenna structures that are hierarchically organized to maximize and direct energy flows in the form of electron-hole pairs (excitons) and electrons and/or holes. The molecular control of the transport of excitons could revolutionize fields in which photon harvesting and energy conversion are key elements. Creation of the required hierarchical supramolecular assemblies with enhanced transport properties will be explored through the use of block copolymer templated chromophores.

Research Accomplishments

Currently, the effort is focusing on chromophore choice and polymer selection and dispersal. The successful dispersal of selected chromophores in target homopolymers and block copolymers has been accomplished. Chromophore 1 and “chlorophyll a” look to be the most promising chromophores at the moment. Due to the H-bonding propensity, most of the dyes dispersed in PS, PMMA, and P2VP, but they did not disperse in PEO and especially not in PDMS. This is useful because previous studies involving graphoepitaxial templates have all been done in PDMS-b-PS diblock copolymers. Interestingly, it has been found that it is possible to use AFM in tapping mode to determine the hidden morphology of the thin film.

Faculty participants and department affiliations: A. Alexander-Katz (DMSE), B. Olsen (Chemical Engineering), C. Ross (DMSE), T. Swager (Chemistry), and M. Baldo (EECS).

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, staffed by a team of highly motivated professionals. During the year ending February 2012, 1,108 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 Research Experience for Teachers (RET) 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.

Several key activities carried out during the past year are detailed below.

A Physical Electronics VersaProbe II Scanning ESCA Microprobe (XPS) with multiple accessories, purchased in May 2011 to serve critical needs of the MIT research community, became operational in the winter of 2012 and is now serving the needs of many CMSE SEF users. The new instrument offers a significant improvement in utility and throughput for XPS users. The current XPS user community includes 37 research groups from nine MIT departments, students from an MIT undergraduate course, and outside academic researchers from Tufts University, Harvard University, Boston College, and Boston University. These users are now being trained on the new instrument.

The SEF staff has been an important element of many of our educational outreach programs and enthusiastically embraces this role. For example, our staff members play a special role in the training of MIT graduate and undergraduate students and our summer educational outreach participants. During this academic year, 202 undergraduate students used the facilities as part of their laboratory subjects. Lab subjects included courses in the Departments of Materials Science and Engineering, Electrical Engineering and Computer Science, Nuclear Science and Engineering, and Earth, Atmospheric, and Planetary Sciences.

SEF staff members offered a number of mini-courses during MIT's 2012 Independent Activities Period (IAP) to train students to operate SEF equipment and apply the latest techniques to their research problems. In January of 2012, a total of 86 students and postdoctoral associates attended courses taught by the SEF staff.

Launch of a New Shared Experimental Facility

On September 1, 2010, CMSE was notified of the award of a $1,837,421 NSF American Recovery and Reinvestment Act grant to renovate laboratories on the third floor of Building 13 and create a new, energy-focused shared experimental facility. The renovation, now about 85% complete, establishes the Nanostructured Materials Growth and Metrology Laboratories (NanoMat Labs), which will be housed within CMSE. A total of 2,900 square feet of wet lab, clean room, and research space was renovated to establish the new facility. The cross-disciplinary interactions that are at the core of CMSE activities will also be reflected in the operation of the new facility, as the NanoMat Labs will be used collaboratively by research groups from materials science and engineering, chemical engineering, electrical engineering and computer science, mechanical engineering, chemistry, and physics, supporting the research activities of over 70 graduate students and postdoctoral fellows. Much of the work performed in the NanoMat Labs will be directed towards the use of nanostructured materials in energy-related projects, with a major focus on photovoltaic structures, batteries, fuel cells, and high-efficiency solid-state lighting. The research tools housed inside the facility will support several large interdisciplinary programs, including the Eni Solar Frontiers Research Center at MIT, the MIT Solar Revolutions Center, the Department of Energy–funded Excitonics Energy Frontier Research Center (EFRC) at MIT, the MIT Solid-State Solar-Thermal Energy Conversion EFRC, and MRSEC. The Eni Solar Frontiers Research Center has provided nearly $1.8 million for the purchase of many of the tools to be housed in this new shared facility. The new facility will operate according to the same business model used in CMSE's other shared experimental facilities. User fees are a source of support for this facility, and fees for instruments housed in the center will be established in the same manner as in the other shared facilities. CMSE has managed shared facilities for over 40 years and has been highly successful with this model of operation.

CMSE has also approved the addition of Room 13-3011 to this new facility. This addition to the NanoMat Labs, renovated with NSF grant funds, will be used to house vacuum deposition equipment that directly supports the mission of the growth and metrology facility. The equipment in this new lab was purchased with industrial support, and a new floor, the addition of a lab window, and wall painting were funded by CMSE.

Collaborations, Outreach, and Knowledge Transfer

Our MRSEC-supported faculty has ongoing collaborations with numerous industrial partners that range from the funding of applied projects (often based on fundamental work carried out within the center) to the development of new technologies and products. We work closely and effectively with MIT programs and centers such as the Materials Processing Center (MPC) and the Industrial Liaison Program (ILP), which connect MIT research to industry. These organizations combined have more than 200 member companies. MRSEC faculty and/or their group members engaged in at least 114 meetings with representatives from a broad range of domestic and foreign companies, including visits from industrial representatives, faculty visits to different firms, briefings with company executives, and teleconferences. A partial list of these companies includes 3M, Bosch, Covidien, Fuji Photo Film Co., LG Electronics, Lockheed Martin, Merck KGaA, Michelin, Raytheon, Royal Dutch/Shell, Siemens AG, and Volkswagen.

CMSE continues its involvement in one of the showcase MIT materials events, the annual Materials Day at MIT organized by MPC. CMSE now contributes significantly to the technical program and poster session. One important objective of this event is to connect MIT materials research to managers and researchers from industry and government laboratories. The title of this year's event was "Computational Materials." Professor Carl Thompson from MPC provided introductory remarks and an overview of the program, with additional talks by professors Markus Buehler, Gerbrand Ceder, and Alfredo Alexander-Katz. The meeting was attended by over 100 registered guests from industry, government laboratories, hospitals, MIT, and other universities, as well as by additional researchers and students from MIT who joined us throughout the day on a walk-in basis. Representatives from over 40 US and foreign companies attended the event, including employees of 3M, the Army Research Laboratory, GE Aviation, the Intel Corporation, the Lord Corporation, and Samsung. The capstone poster event included posters from CMSE students and others from the MIT materials science community. This year, out of a total of 56 posters submitted, 36 were from students and postdocs of faculty supported by CMSE funding. The poster session was judged by a panel of members from MPC's advisory board, which includes research managers from industry.

CMSE continued collaboration with the Department of Materials Science and Engineering and the Materials Processing Center to bring a wide variety of speakers from outside MIT to meet with faculty and students and deliver lectures for the entire MIT community. These lectures typically drew audiences of 80–140 people. In fall 2011, speakers included Bilge Yildiz (MIT), Edward Kramer (University of California, Santa Barbara), Dallas Trinkle (University of Illinois at Urbana-Champaign), Junqiao Wu (University of California, Berkeley), and Eduard Arzt (Leibniz Institute for New Materials). Seminars were limited in spring 2012; however, Charles Lieber (Harvard) did give a talk on "Nanowires: Current and Future Opportunities in Energy and Life Sciences" in May.

MRSEC-supported faculty presented an overview of their research in two ILP-sponsored conferences: the 2011 MIT Research and Development Conference (G. Ceder, T. Lu, K. Van Vliet) and the 2012 MIT in Japan Conference (Y. Fink, K. Hamad-Schifferli). These conferences were attended by over 1,000 individual representatives from companies including 3M, the BMW Group, The Boeing Company, ExxonMobil, General Electric, Gillette, Goodyear, Lockheed Martin, Monsanto Co., Novartis, Philips, Procter and Gamble, Raytheon, and Toyota Motor Corporation.

Another important mechanism for knowledge transfer is the creation of new companies and businesses (and related jobs). Currently active CMSE-related companies that were started by MRSEC faculty, students, or postdocs include OmniGuide Inc., LumArray, Luminus Devices Inc., QD Vision, Kateeva, WiTricity Corporation, and Svaya Nanotechnologies. These various companies were founded to develop novel devices and components based on discoveries made within the MRSEC program and funded, in several cases, exclusively through NSF. Additionally, Nanosys and Quantum Dot Corporation (bought by Invitrogen) are companies whose technology platform is based in part on CMSE-supported fundamental research. It is estimated that total direct

job creation by the most closely CMSE-related companies (OmniGuide, LumArray, Luminus Devices, QD Vision, Kateeva, WiTricity, and Svaya Nanotechnologies) is about 300 jobs and growing.

MIT's Technology Licensing Office is kept aware of new discoveries emanating from CMSE research and helps researchers file patents and issue licenses. Since the start of the current CMSE MRSEC grant, 23 new patents have been issued and 37 new patent applications/provisional patents are pending that are related to MRSEC. In addition, there are currently 18 active industrial, academic, and governmental licenses of CMSE-patented research.

The center's MRSEC-supported faculty enjoy a high level of outside collaboration. During the current MRSEC grant, there have been four MRSEC-related industrial collaborations, 25 collaborations with outside academic researchers, and seven collaborations with government laboratories and agencies. In addition, a number of CMSE faculty members have supervised students in departmental co-op programs that carry out research projects in a wide variety of industrial laboratories.

Professor Ceder collaborates with S. Levasseur (Umicore, Belgium) for synthesis and testing expertise. Professor Nocera and the Jean-Michel Saveant group at the University of Paris Diederot collaborate on fundamental theory of electrochemistry studies at MIT. Professor Thompson works with professor W.K. Choi at the National University of Singapore on the use of metal-catalyzed etching to make silicon nanowires for anodes in Li-ion batteries. He also works with professor O. Kraft and Dr. R. Moenig of the Karlsruhe Institute of Technology on in-situ observations of lithiation of silicon nanowires and lithium oxide growth on carbon fibers. This work is coupled with measurements of the mechanical properties of nanowires before and after lithiation. Professor Thompson also collaborates with professor D. Aurbach and Dr. G. Nessim of Bar-Ilan University on carbon nanotube and nanofiber growth for use in energy storage systems.

Professors Cohen and Rubner collaborate with Dr. Andrew Parker (Oxford University) on biomimetic aspects of optical properties and wetting characteristics of nanostructured materials. Professors Rubner and Cohen also collaborate with M. Beppu (Universidade Estadual de Campinas, Brazil) on the self-assembly of biological polymers into thin films. Students from Brazil come to MIT to work in CMSE labs for periods of six months to a year. Two new students will be coming this spring. Professor Gedik collaborates with Yoichi Ando (Osaka University, Japan), who grows single crystals of topological insulators. Professor Jarillo-Herrero works with professor A. Ishida (Shizuoka University, Japan) on transport in SnTe topological insulators.

Education and Human Resources

CMSE has worked hard to establish a wide-reaching and diverse portfolio of educational outreach programs that are both innovative in nature and responsive to the needs of educators and students. We have now put in place a broad range of well-received

programs that impact high school students and teachers as well as undergraduate and graduate students. Our programs are managed by a full-time education officer who works closely with a faculty education program leader, the center director, and the assistant director.

Besides involvement in CMSE's formal education activities (outlined below), MRSEC-supported faculty, research scientists, and graduate students participate in outreach activities with local schools and with religious communities and professional organizations.

For the past six years, CMSE has collaborated with Roxbury Community College (RCC), a minority-rich two-year college in Boston, to make research experiences available to its students. The objective of this dedicated REU program is to engage community college students in current materials research and encourage them to pursue careers in science and engineering. In 2007, the program was expanded to include students from Bunker Hill Community College (BHCC) as well as RCC. Both colleges have significant enrollments of minority students.

Precollege Education

Materials Research Experience for Teachers

For the past 13 years, CMSE has operated a successful RET 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.
Relationships between CMSE and the RET participants extend beyond the summer program. The teachers bring students to campus and arrange for MRSEC researchers to visit their classrooms.

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

RET Participants, 2011

Name	School/Subject(s) Taught	Research Project or Lesson Plan
Mehmet Bak	Pioneer Charter School of Science, Everett, MA/high school biology	Synthesis of a fluorinated-zwitterionic block copolymer via RAFT (reversible addition-fragmentation chain transfer) polymerization
Karla Brown	Jeremiah E. Burke High School, Boston, MA/biology	Enriched NIR (near-infrared) absorption and emission of metal-organic frameworks for biological and clean energy applications
Christine Horan*	Anova Massachusetts School of Science, Creativity and Leadership, Melrose, MA/middle school science	Using biology to self-assemble materials into filters
Scott Hubeny	East Boston High School, Boston, MA/physics, special education	A smart start to science fairs: helping students create true testable questions for hypothesizing and experimenting
Rory Kondrad	Somerville High School, Somerville, MA/physics	Teaching and learning transient grating spectroscopy
Sean Müller	Merrimack High School, Merrimack, NH/chemistry	Electronics design for student experimentation with materials in electromechanical systems
Kelly Qualman	Anova Massachusetts School of Science, Creativity and Leadership, Melrose, MA/middle school science	Using biology to self-assemble materials into filters

*This teacher's stipend was paid by her host faculty.

Science Teacher Enrichment Program and Women's Technology Program

CMSE offered its Science Teacher Enrichment Program (STEP) for the 10th time in the summer of 2011. The goal of the program is to deepen the teachers' content knowledge in areas related to the stated learning standards. It consists of a one-week, hands-on workshop, "Dustbusting by Design," in which the participants enhance their knowledge of the engineering design process by immersing themselves in it. After considering the special features of a hand-held vacuum, the physics of its operation, and the properties of the materials involved, the participants design and construct motors to meet performance specifications. The program includes presentations on polymers and new battery materials. The final day is devoted to a brainstorming session among the teachers and professor Steven Leeb, CMSE's faculty education leader, about classroom projects to transfer the teachers' experience to their students.

MRSEC supports up to five teachers in this program each year. Participants receive a small stipend and professional development points. They are recruited from local school districts, from former applicants to the RET program, and through alumni of CMSE's education programs. Three teachers participated in the 2011 STEP. One teaches high school physics and chemistry, and the other two teach technology and engineering at the middle school level. The STEP participants completed entrance and exit surveys to give CMSE a sense of how well this workshop met their professional needs. The 2011 respondents indicated that the program provided them with the background to be comfortable and enthusiastic about presenting engineering design material to their students. They also reported that they left with new ideas to take back to their classrooms. One specifically commented, "I have a lot of ideas to develop and several that can be implemented directly."

A companion effort to STEP is CMSE's collaboration in the Women's Technology Program (WTP) in EECS. In this four-week summer residential program, 40 high school girls from across the country take classes in math, computer science, and engineering. The program is designed to address a gender imbalance in the field of engineering by increasing the girls' interest and confidence in pursuing engineering careers. CMSE invites the WTP participants to join the lab portion of STEP to gain hands-on engineering experience. For the past 10 years, this has been an extremely successful collaboration. WTP alumni report that this motor-building lab is an exciting part of the program. CMSE continued to support WTP by providing the curriculum and supplies for this part of the program in 2011 and will continue to do so in 2012.

Workshops and Public Events

MRSEC faculty and students contributed content to a variety of programs and events on campus, at local schools, and at other public venues. For the third consecutive year, Professor Leeb taught a four-session materials and energy class to 25 high school students who were on the MIT campus to participate in the Research Science Institute (RSI). RSI is a well-established national six-week research program for outstanding high school students that is sponsored by the Center for Educational Excellence.

CMSE does not have a formal program to engage high school students in research on campus, but it does match interested students with faculty-led research projects when feasible. Maya Ebsworth, a high school student from the Winsor School in Boston, spent the summer of 2011 working in professor Silvija Gradecak's lab. She conducted research on the chemical growth of zinc oxide nanowires based on hydrothermal synthesis. Ms. Ebsworth presented this research in a poster at the CMSE/MPC poster session in August 2011.

Over the course of the year, CMSE faculty and students presented demonstrations or gave lectures at local K–12 schools, meetings of community organizations, and public programs. Professor Leeb conducted a hands-on program on mechanisms of light generation and strobe photography with a group of 18 Girl Scouts. He taught an activity on light-emitting devices to another group of Girl Scouts. He also conducted a motor-building activity at a science night hosted by the Belmont school department in April.

Two hundred students and parents built simple DC motors at this event. Professor Leeb and a group of undergraduates have contributed to science night annually for several years. In April, CMSE cosponsored a "Science Extravaganza" organized by the MIT student chapter of the Society of Mexican-American Engineers and Scientists. This daylong event brought approximately 250 middle and high school students to MIT to take part in hands-on workshops and lab experiments. The students were recruited from local schools and programs with high Latino enrollments. The purpose of the event was to introduce them to engaging science, engineering, and math projects with the goal of enhancing their interest in these fields. CMSE's contribution to the event was an electrical engineering workshop that taught the students about circuits and electrical components. Finally, each spring, CMSE participates in the annual Cambridge Science Festival, a nine-day, city-wide public celebration showcasing Cambridge as a leader in science, technology, engineering, and math (STEM). It features a wide range of activities, including a science carnival incorporating dozens of hands-on demonstrations. At the 2012 carnival, graduate students will present a group of demonstrations on bubbles, colors, and light. The carnival is typically attended by more than 200 people of all ages.

Science and Engineering Program for Middle School Students

The center has operated a science and engineering program for seventh- and eighth-grade students from two Cambridge public schools for the past 20 summers. The objectives of the program are to introduce students to the field of materials science and engineering, demonstrate that science and engineering can be fun, and provide students with an opportunity to experience a college environment. The program consists of a full summer week of hands-on and inquiry-based science and engineering classes for students from each school. During the summer of 2011, 25 seventh- and eighth-grade students attended with their science teachers. Eight of them were girls, and 17 were 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 2011 program included classes on glassblowing, electrochemical energy, building simple DC motors, magnetism and superconductivity, and electric circuitry. Polymer demonstrations and a presentation on the periodic table were also included. In group discussions at the end of the program, the students were able to explain the material presented during the week and identify new terms they learned during the program. On exit surveys, participants described the program as a fun way to learn, and all of the respondents said they would recommend the program to a friend. Because the students are on campus from 8 am to 3 pm each day, meals are provided by CMSE. The center also provides bus transportation between the schools and the MIT campus.

Undergraduate Education

Undergraduate Research Opportunities Program

The Center provides opportunities for MIT undergraduates to participate in MRSEC research through MIT's Undergraduate Research Opportunities Program (UROP). Participants in this program work on MRSEC research on a part-time basis during the academic year and full time during the summer. MRSEC supports three students each

academic term and three during the summer. UROP students sometimes continue their research beyond one term. Also, MIT provides funding for a limited number of UROP participants, and some of them work on MRSEC research. During the past grant period, MRSEC directly supported eight undergraduates. Two of them were women and two were underrepresented minority students. CMSE faculty report that an additional 10 students (9 of whom were women and 2 of whom were minority students) working on their MRSEC research were supported by MIT directly or worked for academic credit.

CMSE-Funded UROP Students, June 2011–May 2012

Student	Department	Project
Christopher Brathwaite	Materials Science and Engineering	Polymer multilayers for cell surface functionalization
Andrew Carlson	Mechanical Engineering	Next-generation naval propulsion system architecture
Peter Florin	Aeronautics and Astronautics	Growing carbon nanotubes onto carbon fiber to increase tensile strength
Sally Lin	Materials Science and Engineering	Synthesis of a Belousov-Zhabotinsky gel with discrete patches of NIPAAm-Ru(bpy)$_3$
Lucas Orona	Physics	Transport in topological insulators
Stephanie Schafer	Materials Science and Engineering	Study of topological insulator thin films toward spintronic application
Brian Sennett	Electrical Engineering and Computer Science	Water utility monitoring: honing accuracy and field testing
Scott Skirlo	Physics	Optimal symbols for 2D alignment

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 175 applications for the summer of 2011, which were reviewed by a committee consisting of the CMSE director and staff from both centers. Participants were chosen from this pool on the basis of academic performance, interest statements, and faculty references. The 15 students accepted into the program for the summer of 2011 included five women and 10 men, four of whom were from underrepresented minority groups.

The students were paid stipends and worked full time for nine weeks. Most of them lived in a dormitory on campus. Weekly meetings were devoted to research discussions and informal seminars with guest speakers on topics such as the graduate school admissions process, research funding, and intellectual property. The interns completed the program by producing posters that reported on their summer's research. The resulting poster session was held during the final week and was open to the entire MIT community. It included posters produced by participants in CMSE's RET and community college programs as well and served the dual purpose of functioning as a final report by the interns and teachers and informing the broader MIT materials community about the wide range of research supported under the auspices of the two centers. The MPC program is well established as a quality internship program on campus. Consequently, other organizational units seek to fold their summer undergraduate researchers into the program. Last summer, the stipends of two students in the REU program (Amelia Plunk and Thomas Rembert) were paid by the Department of Energy–funded Solid-State Solar-Thermal Energy Conversion Center. These two students were selected from the pool of applicants to the REU program and participated fully in the program.

MPC Summer Interns, 2011

Name	Home Institution/Major	Research Project
Christian Alemán De Leon	Universidad del Turabo/mechanical engineering	Deposition and characterization of nanostructured polypyrrole films grown at distinct centrifugal accelerations
Sara Avila Oneill	Universidad del Turabo/applied mathematics	Frequency-dependent mechanical properties of agarose at the nanoscale deformation
Alejandro Ceballos	Northern Arizona University/physics, mathematics	Characterization of the morphology and magnetic properties of triangular CoFe2O4 nanoplates
Silvia Chan	University of Pennsylvania/materials science and engineering	Constitutive relation for aligned carbon nanotube polymer nanocomposites with controlled morphology
Michael Christiansen	Arizona State University/physics	Carbon nanotube electrodes for capacitive deionization
Kevin Cunningham	University of Massachusetts, Amherst/ chemical engineering	Characterizing the microstructure of a corrosion-resistant alloy
Chad Hunter	University of Rochester/chemical engineering	Layer-by-layer assembled membranes for solar-powered water electrolysis applications

Keith Motes	Louisiana State University/physics	Capacitive touch sensing using smart fibers
D. Evan Piephoff	North Carolina State University/chemical engineering	Coupling and rectification in single-walled carbon nanotube/graphene junctions: investigation and applications
Amelia Plunk	Mt. Holyoke College/physics	Examining the stability of nanocrystalline W-Cr
Thomas Rembert	University of Arkansas/electrical engineering, physics	Modeling the response of superconducting nanowire single-photon detectors with COMSOL
Alina Sabanska	City College of New York/mechanical engineering	Developing nanoengineered surfaces and coating technologies for scale prevention
Edgardo Vazquez Rodriguez	Universidad Metropolitana/applied mathematics in biology	Hierarchical analysis of music and spider silk using category theory
Jacob Wagner	Case Western Reserve University/ polymer science, chemistry, physics	Crowding-induced collagen alignment
Kelilah Wolkowicz	Roger Williams University/engineering (mechanical engineering specialization)	Injectable pH-dependent MR (magnetoresistive) sensors

The results of the cross-site REU assessment indicate that the CMSE REU program had a positive impact on students' professional development and their career plans. All of the interns rated the REU experience overall as either good or excellent, and 89% felt their summer research experience increased their confidence in their ability to contribute to science. In addition, all of the participants said that the experience confirmed their interest in their chosen field of study, and all felt that the program prepared them for graduate school.

REU (Research Experiences for Undergraduates) participants

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 Program

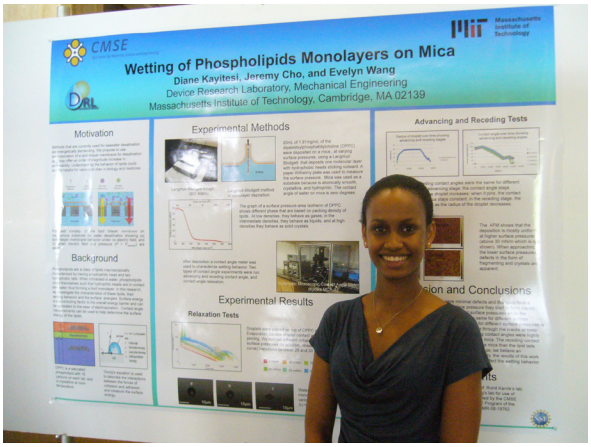
CMSE's Community College Program (CCP) is another targeted REU program designed to enhance the diversity of undergraduate participants in the MRSEC's research and education programs and to broaden participation among science and engineering professionals. Four students from two local community colleges that enroll significant numbers of minority students (40% at one and 55% at the other) participate in CCP each summer. Over the seven years that the program has been in place, 68% of the participants have been minority students and 55% have been women. Typically, community college students do not have opportunities to gain research experience at their home institutions. By participating in CCP, they learn research and technical lab skills that increase their confidence and prepare them to pursue bachelor's degrees and science and engineering careers. The program also broadens their view of science and engineering. Through its expanded partnership with Bunker Hill Community College, CMSE invites academic classes to tour the SEFs to learn about the instruments in the labs and how they are used for research. To date, BHCC faculty have brought a diverse group of 111 of their students to CMSE. The faculty has indicated that, in addition to learning about how the sophisticated tools in the SEFs support research, the students are introduced to a broader range of science and engineering career options than those with which they are familiar. These tours also provide a chance to talk with the students about possible participation in CCP.

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

Community College Program Participants, 2011

Name	Home Institution/Major	Research Project
Adekemi Adeleye	Roxbury Community College/nursing	Engineering novel biomaterials at the nanoscale
Diane Kayitesi	Bunker Hill Community College/ engineering	Wetting of phospholipid monolayers on mica
Hanna Seat Byeul Lee	Roxbury Community College/ biological sciences	Mucin gene expression during development in the zebrafish *Danio rerio* using qRT-PCR
David Woerner	Bunker Hill Community College/ engineering	THz time-domain spectroscopy of solids

During summer 2011, two RCC students and two Bunker Hill students, including two African Americans and three women, participated in the program. Since its inception in 2005, 31 students have participated in CCP; 71% of them have enrolled in bachelor's programs. Four of those students are currently pursuing graduate degrees in science or engineering and one is in medical school. Two additional CCP students are currently working in technical fields.



Bunker Hill Community College student Diane Kayitesi presents her research poster at the 2011 Research Experiences for Undergraduates/Research Experience for Teachers poster session.

Partnership with Universidad Metropolitana

Through a partnership with the Universidad Metropolitana (UMET) in San Juan, Puerto Rico, CMSE enhances the research experiences of students at Puerto Rican universities. Dr. Juan Arratia at UMET helps identify and recruit undergraduates from the three universities affiliated with the Ana G. Mendez University System (UMET, Universidad del Turabo, and Universidad del Este) to participate in the MPC Summer Internship Program. At least two intern positions are dedicated to students from UMET and its affiliated institutions. Three students participated in the 2011 internship program. A goal of the UMET partnership is to recruit and retain Puerto Rican science, technology, and engineering graduates. Since its inception, eight students have participated in the program, and an additional two students spent two weeks at CMSE working with graduate students to learn to use research instruments in the SEFs. Five of the students are still completing their undergraduate studies. Of the others, one is currently working at the Goddard Space Flight Center, one is working at an engineering firm, one is a materials science and engineering graduate student at Rutgers University, and a fourth will begin working on an MS degree at the Polytechnic University of Puerto Rico. In addition to their research at MIT, undergraduates who participate in the program contribute to UMET's outreach to high school students in the San Juan area. The objective of this well-established UMET outreach component is to enthuse and encourage younger students to pursue higher education in science, technology, engineering, and math.

In an effort to recruit REU participants from institutions that have significant numbers of students from underrepresented groups, CMSE directly advertises the program to minority-serving institutions. In the fall of 2011, 500 letters with attached recruitment posters were emailed to principal investigators at NSF-funded Centers of Research Excellence in Science and Technology and Historically Black College and University Undergraduate Programs, as well as to recipients of Broadening Participation Research Initiation Grants in Engineering. For the past few years, CMSE has also advertised its REU program via the Institute for Broadening Participation's online directory of REU programs. Finally, the center encourages former minority participants to refer other students at their home institutions to the internship program. Although the number of applications from women and minority students has been gradually increasing since the beginning of the grant, applications for the 2012 program show a decline. Of the 186 summer internship applications, 18% were from women and 8% were from minority students. The CMSE education officer plans to work with student chapters of minority and female professional science and engineering organizations at MIT to help recruit applicants from their memberships on other campuses. To further increase diversity in the REU program, the center, as mentioned, runs collaborative programs with two local community colleges and the Universidad Metropolitana, all of which serve underrepresented minority students

With regard to K–12 education, and expanding the pipeline of a diverse group of future scientists and engineers, CMSE seeks to impact the classroom experience of a large number of minority students by strengthening the materials content knowledge of their science teachers. For the RET program, the center is committed to at least 50% participation by teachers from schools attended by significant numbers of underrepresented students (above 50%). Four of the seven teachers in the 2011 RET program were from such school districts in Massachusetts (two from Boston, one from Everett, and one from Somerville). Through the Science and Engineering Program for Middle School Students, CMSE directly engages local middle school students. Students for this program are drawn from two Cambridge public schools where approximately 50% of the registered students are from underrepresented minority groups. Consequently, although the number of female and minority program attendees varies from year to year, the program reliably reaches a diverse group of young people. Average participation in this program over the three years of the current grant is 40% female students and 60% minority students. In the summer of 2011, 32% of the participants were girls and 68% were minority students.

An event designed to attract minority undergraduates from North Carolina A&T State University (NCA&T) to graduate studies resulted from CMSE's participation in a leadership development institute (LDI) last summer. Dr. Elham Fini, assistant professor of civil engineering at NCA&T, spent the summer of 2011 engaged in research with Professor Buehler as a participant in an NSF-funded LDI conducted by the Quality Education for Minorities (QEM) Network. The objectives of the LDI were to enhance the leadership and research capabilities of STEM faculty at Historically Black Colleges and Universities and to build a community of emerging leaders in STEM at these institutions. QEM provided Dr. Fini's stipend, housing, and travel costs. CMSE provided

an office and funds for supplies and use of equipment in the course of her research. Dr. Fini and Professor Buehler continue to collaborate. As a result of her experience at MIT, Dr. Fini arranged a workshop and information session for 13 of her NCA&T students that was cosponsored by CMSE. On October 24, the students visited the Institute to get a sense of the teaching and learning environment at research-intensive universities such as MIT. Professor Rubner presented an overview of the center's research and education programs, highlighting the summer internship program as a great way to preview the graduate research experience. Professor Buehler talked about several inspiring research projects in the field of civil engineering, and other Civil Engineering faculty spoke about graduate study programs in their department. Professor Ortiz shared her personal career development experiences and her passion for an academic career. Finally, the Office of the Dean for Graduate Education presented a "Grad School Clinic" to provide the visiting students with guidance on selecting a graduate school, choosing a field of study, and preparing graduate school applications. As a direct result of conversations that day, one of the NCA&T students applied and was admitted to CMSE's REU program.

Professor Elham Fini with North Carolina A&T State University students visiting MIT.

Postdoctoral Mentoring

A total of 25 postdoctoral associates worked on CMSE research during the past year, 14 of whom were paid with MRSEC funds. CMSE launched a postdoc mentoring program in 2010 with a director-led meeting of CMSE postdocs to identify their professional development needs and topics they would like to see addressed. As a result, a postdoc advisory committee was formed. In 2011, CMSE launched a mentoring seminar series that features annual professional development events jointly sponsored by CMSE and a related MIT academic department. All postdocs working with CMSE faculty are invited to participate in the seminars, whether or not they are supported by MRSEC. The first seminar, held in January of that year, was cohosted by DMSE and focused on career paths and balancing professional and family lives. A panel consisting of two DMSE faculty (professors Christopher Schuh and Angela Belcher) and two former MIT postdocs now working in industry (Dr. Ayush Verma of Novartis and Dr. Alan Lund of Xtalic Corp.) shared their personal career stories and described how specific decisions impacted their careers and their strategies for managing successful work and family lives. The event was attended by 25 postdocs. On exit surveys, attendees provided a list of topics for future seminars.

Postdocs participating with faculty panel at Landing That Next Position seminar.

The second seminar, "Landing That Next Position: Strategies for Finding and Securing a Faculty Position," took place in January 2012. CMSE partnered with the Department of Chemical Engineering to present a panel of faculty who offered advice on strategies for applying for and obtaining a faculty position, including negotiating a starting salary and startup package. The seminar was attended by 50 postdocs. The panel consisted of professors Paula Hammond, Bradley Olsen, Gregory Stephanopoulos, and Michael Strano. The panel discussion was followed by a social hour for one-on-one conversations and informal networking. Feedback from the attendees indicates that the program was successful and that they found it helpful to hear about the personal experiences of the faculty. The postdocs also expressed their appreciation for the opportunity to get together and focus on career issues. CMSE will continue to partner with different academic departments to offer postdoc seminars in the future and to draw on its postdoc advisory committee to identify relevant topics for future seminars and programs.

Administration, Management, and Research

Our MRSEC program is administered by a proactive and effective management team that responds quickly to emerging needs of the program. Currently, seven administrative and seven SEF staff support the program. Administrative staff include an education officer, facilities and safety coordinator, financial administrator, financial and operations assistant, assistant to the director, assistant director, and director. SEF staff include one technical associate, four research specialists, a project technician, and a research scientist. The CMSE director reports directly to the vice president for research and associate provost, the assistant director reports to the director, and all other staff, including the facilities manager, report to the assistant director. Our current director also serves as CMSE's chemical hygiene officer. CMSE currently has a faculty education program leader who marshals our educational outreach plans with our education officer.

CMSE Junior Faculty Award for Shared Experimental Facility Use

CMSE, recognizing the financial burden MIT junior faculty face in utilizing large experimental facilities for research needs, launched the CMSE Junior Faculty SEF Award program in 2011 to assist these faculty members in accessing the CMSE shared experimental facilities. The faculty who were awarded funds during 2011 found the program very helpful, and it has been decided to continue the program into the future and extend each award for a two-year period, allowing more time for the junior faculty members to use this funding. Contingent on the availability of center discretionary funds (this program is supported by funds distributed to CMSE from technology licensing revenue), CMSE will fund five to seven individual awards per year to MIT assistant professors at a level as high as $5,000 for each award. Each award will last for two years and can be applied only to user fees in CMSE shared experimental facilities. These awards are restricted to faculty engaged in research activities related to aspects of materials science and engineering as practiced at CMSE. One- to two-page research proposals for these awards will continue to be solicited from junior faculty throughout the MIT materials community each year and reviewed by the center director, who will make awards based on the strength of the faculty proposal and the financial need justification. The following MIT junior faculty (assistant professors) received these awards for 2012, with more awards possible during the year:

Polina Anikeeva, DMSE

Silvija Gradecak, DMSE

Jeremiah Johnson, Chemistry

William Tisdale, Chemical Engineering

CMSE has continued to support the joint CMSE/DMSE colloquium series started in 2005 with the Department of Materials Science and Engineering and expanded in 2007 to include the Materials Processing Center. The DMSE/CMSE/MPC partnership allows the center to pool resources and bring in speakers from outside of MIT. The objectives of the colloquium series are to provide an opportunity for faculty, research staff, and students from different disciplines to meet on a regular basis to hear about the latest breakthroughs in materials research and to inform the greater MIT community about materials research. As mentioned, fall 2011 speakers included Bilge Yildiz, Edward Kramer, Dallas Trinkle, Junqiao Wu, and Eduard Arzt; Charles Lieber spoke in spring 2012.

CMSE also hosts the MIT-wide Facilities Managers Group. This group was formed to better coordinate the synergistic activities of the large materials community at MIT. The CMSE director and one of the CMSE SEF managers, chosen each year by the CMSE director, chair the group, and meeting arrangements are made by CMSE headquarters staff. A meeting with facility managers is planned for the fall of 2012 to allow discussion of the CMSE experience with the CORAL (common object representation for advanced laboratories) facilities lab management program in the CMSE shared experimental facilities. The rollout of this comprehensive lab management system, which includes online user registration, real-time instrument status and a complete billing module, is now complete in all of the CMSE shared experimental facilities.

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

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