Department of Materials Science and Engineering

The Department of Materials Science and Engineering (DMSE) has completed another memorable year; among the notable moments were the excitement of moving into new headquarters in Building 6 with greatly improved meeting and display spaces, the celebration of our largest ever group of graduates in June, and our deep gratitude to Vasilios Salapatas (PhD '66) and Danae Salapatas for a generous gift that will enable us to begin construction on a laboratory for advanced materials and to endow three graduate fellowships. There was a note of sadness, however, as professor Walter S. Owen, head of the department from 1973 to 1982, died in October.

Our new facilities lend themselves to seminars, meetings, and student presentations. One such activity is the MIT and DOW Materials Engineering Contest (MADMEC), which began in AY2007 supported by a gift from Dow Corporation; the winning teams have shown great initiative in continuing their projects by pursuing patents and technology transfer. For the AY2008 contest, GM and Saint-Gobain have joined Dow as corporate sponsors. Five student teams are busy designing and prototyping devices that harness, store, or exploit sources of alternative energy through principles of materials science and engineering and will present their final projects this fall.

With support from the Lord Foundation, we have expanded this and other programs through the creation of a Rapid Fabrication Laboratory (RFL) that contains CAD-controlled lathes and cutters, 3D printers, and water-jet and laser cutters for students' use. Enthusiastic undergraduates are also using the RFL to complete assignments for laboratory subjects. We continue to equip this lab.

Research Initiatives

Materials science and engineering is primed to meet the 21st-century challenges of intensive global competition, increasing carbon emissions, health threats, and a population drawing from a finite resource base. Materials and materials practitioners can change the nature of commerce, the interaction with the environment, and the character of resource use. Department researchers are pursuing collaborations throughout MIT and at other institutions, particularly in the areas of energy storage, environmental remediation, and cancer research. We present current research via seminars to graduate students, presentations to peers during faculty meetings, and, in a new offering this year, in half-day "microsymposia" with panel discussions and demonstrations. This Frontiers of Materials Science series focuses on the role of materials in addressing the energy crisis and is attended by graduate students, alumni, and researchers from other institutions.

Undergraduate Education

We were pleased to pass the Accreditation Board for Engineering and Technology (ABET) accreditation successfully, with no areas of concern. Even so, we are assessing our undergraduate curriculum, last revised in AY2003, to ensure that it prepares our students for fulfilling careers, whether in academia or industry.

DMSE's undergraduate enrollment stands at 95 students, with 46 percent women, 21 percent underrepresented minorities, and 6.4 percent international students. Eight students are designated Course 3A (a more flexible degree program designed for premed, business, or law students). The internship program continues to attract a large portion of DMSE undergraduates; 28 DMSE rising seniors and juniors are working at 24 host institutions at 26 locations for summer 2008, including six overseas institutions.

Undergraduate recruiting efforts were very successful this year; in addition to our customary efforts of participating in Academic Expo and Exploring the Majors Fair, hosting open houses, sponsoring the semiannual John Wulff Lectures, and offering freshman advising seminars and independent activities period (IAP) activities, this year DMSE undergraduates took a significant role in reaching out to their peers. In the future, they plan further activities such as a research day in which seminars will be given by participants in the Undergraduate Research Opportunity Program, graduate research assistants, faculty, and alumni to show some of the scope of possibilities open to students of materials science. In fall 2007, DMSE offered four freshman advising seminars, staffed by professors Samuel Allen, James Livingston, Kenneth Russell, and Edwin Thomas; DMSE has an ongoing commitment to offering these seminars—one has been taught since 1985.

Graduate Education

The department has a very healthy graduate student enrollment, numbering 227 in fall 2007. Approximately 33 percent of the graduate students are women and two percent are underrepresented minorities. The Program in Polymer Science and Technology has 16 enrolled students, four students are in the Leaders for Manufacturing program, and five have entered the health sciences and technology program. For fall 2008, we anticipate an incoming class of 65, of whom approximately 38 percent are domestic students.

Starting its second year in AY2008, the teaching minor program has attracted several doctoral students who are completing the recommended 24-unit load, including 3.69 Teaching Fellows Seminar, taught by professors Christopher Schuh and Edwin Thomas, which helps them prepare for teaching at an advanced level. This program provides the department with knowledgeable teaching assistants and is invaluable for students planning careers in academia.

Our Master of Engineering program is in its seventh year with 75 alumni/ae. In September 2008, 26 students will graduate, and 14 students are expected to enroll for the coming academic year.

Student Organizations

Officers of the Society of Undergraduate Materials Scientists (SUMS) for 2008–09 are president Dian C. Ariesta, career development chair Christine Lee, material advantage chair Ryan K. Bonaparte, publicity chairs Phyllis Xu and Michele Lee, recruiting chair Richard Lin; social chair Siamrut Patanavanich, and webmaster Jeffry Disko. SUMS officers are taking an active role in the department, including helping with freshman recruiting and making presentations to the visiting committee. They have also set up new resources to help their peers by creating a career development chair to present

and publicize career opportunities and a membership in Material Advantage, a student program that provides access to professional societies for materials scientists.

The Graduate Materials Council (GMC) officers for 2009 will be president George Whitfield; vice-president Timothy Zens; treasurer Tim Chin; Departmental Committee on Graduate Students/Graduate Student Council (GSC) representatives Charles Moore, Gagan Saini, and Tiffany Ziebell; social chairs Sal Barriga, Agustin Mohedas, Kevin Huang, Anubhav Jain, and Michiel Vanhoutte; academic chair Karen Shu; alumni relations chair Megan Brewster; and athletics chair Matt Smith. GMC activities this year included taking a trip to George's Island in Boston Harbor during graduate student orientation and sponsoring monthly themed socials. GMC's hard work is invaluable during the spring Hosting Weekends when the department introduces itself to admitted potential graduate students; they make themselves available to answer questions, give tours, and be a welcoming presence. Socials during Hosting 2008 included contests for best research image and best research movie, open to the admitted students.

Our students continue to be active in outreach roles. Megan Brewster directed the MIT Women's Initiative (WI), which is dedicated to engineering outreach to 6th- to 12th-grade girls across the nation. The 2008 WI presenters are both grad students and undergrads, from six School of Engineering departments, who receive training in the fall before traveling during IAP to schools that have applied to be in the program. In 2008, Ms. Brewster went to Hawaii where she made 20 presentations on four different islands.

Graduate students Scott Litzelman and George Whitfield, with professor Harry Tuller, presented a science lesson with hands-on activities at the Lynnhurst Elementary School in Saugus, MA. They spoke about global warming, energy, the environment, and careers in science. The fifth graders participated in hands-on fuel cell, solar cell, and thermoelectric experiments and were presented with "Jr. Scientist" certificates.

Emily B. Walton was a presenter at "Redefining the MIT Classroom," a workshop celebrating MIT faculty achievements in a forum for discussing and exchanging innovative ideas about teaching and learning. Ms. Walton's talk, "Students Create the World's Largest Human Genome Model," was the only one presented by a graduate student; all other presenters were faculty, deans, and educationalists.

Personnel

We welcome three new faculty members for fall 2008. Professor Alfredo Alexander-Katz earned a BS in physics from Universidad Nacional Autónoma de México in 1998 and a PhD in physics from the University of California, Santa Barbara, in 2004. His doctoral work focused on understanding the self-assembly of copolymers by using novel field-theoretical methods. Afterward, he moved to Munich as a National Science Foundation (NSF) International Postdoctoral Fellow to study the dynamics of driven polymers. His work in Munich led to an important discovery that unraveled the mystery behind the process of blood clotting at high shear rates and opened new routes for the development of novel shear responsive materials. He later moved to the École Supérieure de Physique et Chimie Industrielle in Paris as a Centre National de la Recherche Scientifique postdoctoral researcher to study charged polymer solutions and their self-assembly, with

direct applications to fuel cells. His current interests lie in the realm of self-assembly and dynamics of biological soft materials using a combination of analytical theory and simulations. His group is particularly focused on designing novel polymer-like drug delivery carriers and understanding their response to chemical and physical stimuli. This work aims to enable a new generation of drug delivery vectors that could target different areas of the body in a very specific manner and to provide a much deeper understanding of the processes of adhesion and targeting in flow. Other topics that he is pursuing are understanding the supramolecular self-assembly of chlorophylls in the antennas of photosynthetic bacteria, the most efficient light-harvesting organisms on Earth, as well as studying the dynamics of driven soft systems in general. The research in professor Alfredo Alexander-Katz's group is highly interdisciplinary and lies at the interface of materials, biology, physics, chemistry, and medicine.

Professor Geoffrey Beach earned a BS in physics from the California Institute of Technology in 1997 and a PhD in physics in 2003 from the University of California, San Diego, where he worked in the Center for Magnetic Recording Research to develop novel magnetic thin-film nanocomposites for ultrafast data storage applications. He then went on to the University of Texas at Austin as a postdoctoral fellow in the Department of Physics and the Texas Materials Institute where he made important discoveries in magnetization dynamics and spin-transfer torque in nanoscale magnetic structures. His current research interests focus on spin dynamics and spin-electronics in nanoscale magnetic materials and devices. Developing ways to store information more densely and to access it more quickly requires understanding the magnetization configurations in nanoscale structures and how they evolve in time. His work aims in part to understand and control spin excitations in magnetic materials whose dimensions approach fundamental magnetic length scales. One of the most exciting prospects in magnetism today is the possibility of electrical control of the magnetic state of a device, taking advantage of the coupling between spin and charge in a conducting ferromagnetic material. A major thrust of his research aims to harness the spin of the electron in magnetic materials to realize new approaches to spin-based storage and computation. Studying these processes requires the development of advanced instrumentation capable of probing magnetization dynamics at the shortest timescales and the smallest length scales. His group will work to develop optical and electrical approaches to push the detection limits to enable development of new materials and structures to meet the information storage and processing demands of the future.

Professor Michael Demkowicz studies the fundamental processes by which solids change their atomic structure when driven far from equilibrium—for example, when plastically deformed, bombarded by energetic ions, shocked, or exposed to environmental extremes such as rapidly varying temperatures and pressures. Understanding how materials respond to these external stimuli can be used to create strategies for designing materials with desired properties from the atomic scale up. His recent work has focused on nanocomposites under intense irradiation. Traditional structural materials degrade and fail under these conditions, but certain nanocomposites contain high-volume fractions of "super sink" interfaces that allow them to self-heal. By understanding how radiation damage is trapped and removed at such interfaces, Professor Demkowicz aims to enable the design of a new class of radiation-tolerant

materials that would make future nuclear reactors maximally safe, sustainable, and efficient. Another avenue of research pursued by professor Michael Demkowicz is in understanding the mechanical and transport properties of glasses. This class of materials differs fundamentally from crystalline solids in that it possesses no long-range lattice periodicity. The behavior of glasses therefore not only poses a challenge to our current understanding of materials but also offers opportunities for creating new materials that circumvent the drawbacks of traditional ones at the atomic level. Other areas of current interest include shock physics, nanoscale cellular materials (open and closed cell nanofoams), response of interfaces to severe plastic deformation, and the behavior of materials in extreme environments.

Professor Yang Shao-Horn will begin a joint appointment with DMSE on July 1. Her research on materials for electrochemical energy storage and conversion strongly connects to many collaborative efforts with personnel in our department.

Dr. Robert C. O'Handley retired in February from his position as senior research scientist in DMSE and the Materials Processing Center (MPC). Dr. O'Handley joined MIT in 1981 as research scientist working with professor Nick Grant on applications of metallic glasses. Although officially retired, he will remain actively engaged with research and development through his role at Ferro Solutions and his relationships with MIT colleagues.

Professor Lorna J. Gibson will step down from the associate provost office effective July 1. During a sabbatical this coming academic year, she will coauthor *Cellular Solids: Biomechanics and Biomaterials* with MF Ashby and BA Harley.

In August, professor Lionel C. Kimerling will step down from the role of MPC director and professor Carl V. Thompson will take on the position.

Professor Christine Ortiz is now director of the MIT International Science and Technology Initiatives MIT–Israel program.

Su Chung assumed the role of director of the Administrative Services Organization in July 2007. In June, Coleman Greene, systems administrator, left MIT to pursue other opportunities.

Research Highlights

In this year's report, the department is profiling exciting research from four of its faculty members.

Professor Yoel Fink's research has led to the discovery of a new class of composite fiber materials composed of conductors, semiconductors, and insulators. Unlike any other fibers, they share the basic device attributes of their traditional electronic and optoelectronic counterparts yet are fabricated by conventional preform-based fiber-processing methods, yielding kilometers of functional fiber devices. Two complementary approaches toward realizing sophisticated functions are explored: at the single-fiber level, the integration of a multiplicity of functional components into one fiber and, at the

multiple-fiber level, the assembly of large-scale two- and three-dimensional geometric constructs made of many fibers. When applied together, these approaches pave the way to fibers and fabrics with new types of functions. Professor Fink's research has been central to the renewal of the NSF Materials Research Science and Engineering Center at MIT.

In the past year, his group has reported on a new type of flow instability central to the fiber processing approach; using this instability, semiconductor wires with an unprecedented aspect ratio have been fabricated within fibers. His group has also disclosed the first single-fiber logic gate. The fiber logic structure was realized in a two-step process: first, the simultaneous drawing of metals, insulators, and semiconductors from the viscous state leads to the smooth isomorphic mapping of geometrically elaborate macroscopic preforms to arbitrarily long microscopic fibers. Photonic bandgap fibers developed in his group and licensed to OmniGuide, Inc., over the past year have been used to treat more than 4,000 patients in the United States and Europe. These fibers are used surgically to remove head and neck cancer, to manage life-threatening papilloma disease in children, and in surgery to restore hearing. In 2008 alone, more than 1,000 OmniGuide-enabled otology surgeries were successfully completed.

Professor Randolph Kirchain's group applies systems modeling methods to quantify strategic properties of materials, including economic and environmental performance. Concerning economic performance, research has generated the most comprehensive map to date of the cost and value consequences of alternative materials for reducing vehicle mass and improving vehicle fuel economy. This work has revealed that conventional analyses dissuade the adoption of lightweight materials by failing to account for their cost advantages in development, perceived value to the consumer, and ability to reduce exposure to future demand uncertainty.

On the environmental front, professor Kirchain's group has developed models to identify strategies to increase the recycling potential of a materials system including strategies for raw material sourcing, alloy selection, and alloy design. Through extension of these models, recent research results concerning operational uncertainty show that recycling could be increased with no technological change simply by using better decision support methods that take into account the full complexity of the operating environment. More recently, the group is focusing on generalizing these models so that they can be used for any materials recovery system (e.g., polymers, paper, glass) and even for the primary production of numerous biological materials (e.g., collagen, rubber).

Professor Donald R. Sadoway's research seeks to establish the scientific underpinnings for technologies that make efficient use of energy and natural resources in an environmentally sound manner. This effort spans engineering applications and the supportive fundamental science. The overarching theme of his work is electrochemistry in nonaqueous media and specific topics in applied research are the following: environmentally sound electrochemical extraction and recycling of metals, lithium solid-polymer-electrolyte batteries for portable power, high-amperage energy storage devices for stationary applications, advanced materials for use as electrodes in fused-salt electrolysis cells and batteries, electrochemical synthesis of compound semiconductors, and electrochemical synthesis of diamond coatings. The related fundamental research is

the physical chemistry and electrochemistry of molten salts (including molten oxides), cryogenic electrolytes, and solid polymer electrolytes.

One of the Sadoway group's projects is on production of oxygen by electrolysis of molten lunar regolith simulant, as demonstrated in a laboratory-scale cell fitted with an inert anode constructed of material developed for this purpose. The process has the prospect of paving the way to achieve the NASA benchmark for support of a lunar base. Another of his projects is a novel electrochemical energy storage device comprising liquid metal electrodes separated by a fused-salt electrolyte. The device provides a means to exchange (store and deliver) electrical energy at very high amperage. The heart of the invention is discovery of ambipolar metal electrolysis—that is, production of two different metals, one on each electrode. Professor Sadoway has also demonstrated feasibility of carbon-free steelmaking by molten oxide electrolysis in a laboratory-scale cell in which a melt comprising iron oxide dissolved in molten CaO-MgO-SiO_2 was decomposed by the action of electric current into molten iron and oxygen gas. Operating at a temperature of 1,575°C, the process generates no greenhouse gases and boasts unprecedented metal production rates, as high as 15 times that of an aluminum smelter. The process has applicability to other metals, including titanium, nickel, chromium, and manganese.

Professor Francesco Stellacci's research effort is centered on investigating supramolecular surfaces; specifically, he studies the interaction of surfaces with a specific nanostructure with their outside molecular environment. It is well known that nanostructured surfaces are abundant in nature; in fact, they constitute the outside shell of any folded protein. To date, there is no clear understanding of the role of these naturally occurring surfaces in determining physicochemical properties. Several years ago, the Stellacci group found that gold nanoparticles coated with a mixture of hydrophobic and hydrophilic molecules spontaneously form surfaces that resemble those of proteins. In collaboration with professor Darrell Irvine, professor Stellacci has established that a subclass of these particles can penetrate cell membranes as peptides do. This is the first class of synthetic material to show this property. More recently the Stellacci group has found that this surface structure can increase catalytic activity in a way that resembles the function of enzymatic surfaces.

In a parallel effort, professor Stellacci's group in collaboration with professor Jing Kong's group (Electrical Engineering and Computer Science) has developed a material that can efficiently adsorb hydrophobic liquids from water surfaces. This material repels water via the "lotus leaf effect" but adsorbs all liquids immiscible with water by capillarity actions due to its paper-like structure. This material could be ideal for treating water after environmental disasters or for purifying industrially contaminated waters.

Awards and Honors

Professor Samuel Allen was named the 2008 recipient of the Capers and Marion McDonald Award for Excellence in Mentoring and Advising.

Professor Angela Belcher presented the 2008 Smith Lecture at Davidson College in North Carolina. Her talk was entitled "From Nature and Back Again: Giving New Life to Materials for Energy, Electronics, and the Environment."

Professor W. Craig Carter was named a MacVicar Fellow; he also received the SoE Bose Teaching Award.

Professor Silvija Gradecak is a 2008 recipient of the NSF Career Award; her Career project addresses a key materials challenge of nanoscale science and engineering: functionality of novel nanomaterials will be dictated chiefly by our ability to precisely control material structural properties, size, uniformity, and dopant distribution at the atomic level.

Professor Darrell Irvine was named a Howard Hughes Medical Institute Investigator.

Professor Klavs F. Jensen is among the new fellows recently elected to the American Academy of Arts and Sciences.

Professor Nicola Marzari has been named the R.P. Feynman Chair of Nanosciences at the University of Addis Ababa, where he is spending a sabbatical that began in January.

Professor Chris Schuh has been invited to participate in the National Academy of Engineering 2008 Frontiers of Engineering symposium. The event will bring together engineers ages 30 to 45 who are performing exceptional engineering research and technical work in a variety of disciplines.

Professor Francesco Stellacci was a winner of Nanotech Brief's third annual Nano 50™ Awards, which recognize the top 50 technologies, products, and innovators that have had a significant impact—or are expected to—on the state of the art in nanotechnology.

The Materials Research Society has announced its first group of fellows; the 34 newly recognized fellows include professors Subra Suresh, Edwin Thomas, and Carl Thompson.

Professor Subra Suresh was chosen by the Society of Engineering Science to receive the A.C. Eringen Medal for 2008, awarded in recognition of "sustained outstanding achievements in engineering science."

Professor Krystyn J. Van Vliet received a DuPont Young Investigator Award, an award given to professors at the early stage of their careers who have exhibited promise in fundamental polymer science and chemistry.

David Bono, Teri Chung, and Diane Rose are recipients of SoE Infinite Mile Awards for Excellence. Mr. Bono, the manager of the undergraduate teaching lab, is a bottomless resource to undergraduates, whether in the laboratory or working on a MADMEC submission. Ms. Chung, an administrative assistant in professor Harry Tuller's group, is responsible for managing the team's research, educational, and outreach activities as well as initiating and coordinating activities to promote science-related interest in local public schools. Ms. Rose currently works for professors David Roylance, Kenneth Russell, and Bernhardt Wuensch; she has worked in the department since 2000. She is particularly recognized for her ability to undertake major tasks for DMSE, recently assuming a major part of the burden in assembling reports for ABET submission.

Undergraduate Awards

Talia Gershon was awarded a Gates Scholarship to Cambridge University, where she plans to pursue a PhD in materials, in the area of solar cell materials. Ms. Gershon won the Course 3 Best Internship Report Award for "Blends of Thiophene-Based Dendrimers with Titania Nanoparticles for Use in Organic Photovoltaic Devices." She spent last summer at the National Renewable Energy Laboratory in an internship through the Office of Science, US Department of Energy Science Undergraduate Laboratory Internship Program.

Allison Kunz was recognized with the Horace A. Lubin Prize for Outstanding Service to the DMSE Community. Ms. Kunz's activities during her undergraduate career include serving as SUMS president and president of the MIT Laboratory for Chocolate Science.

Awards to the outstanding seniors were made to John Rogosic and Mirat Shah.

Recipients of the outstanding junior awards were Pantea Khodami and Reid Van Lehn.

Outstanding sophomores were Jeffry Disko and Bryn Waldwick.

Graduate Awards

Salvador Barriga and Robert Mitchell were awarded Xerox Fellowships for underrepresented minorities to pursue research in green processes and technologies, imaging and smart documents, and nanotechnology and MEMS.

Megan Brewster received a National Defense Science and Engineering Graduate Fellowship.

Jing Cheng received a Martin Fellowship in the coming academic year.

Noemie Chocat and Aparna Singh received H.F. Taylor Fellowships.

Juejun Hu received the Newport Spectra-Physics Research Excellence Award presented at the SPIE Photonics West conference.

Anubhav Jain was awarded a Department of Energy Computational Science Graduate Fellowship.

Gerardo Jose la O' was invited to be the keynote speaker at the 2008 Blue Lobster Bowl, a local site for the Consortium for Oceanographic Research and Education high school competition. Mr. la O' was asked to speak in recognition of his work with First Step Coral, a project to stabilize the coral reefs in his native Philippines.

Kevin McComber received MIT's William L. Stewart, Jr., Award in recognition of his dedication as GSC Activities Committee cochair.

Xing Sheng received a DuPont–MIT Presidential Fellowship for 2007–08.

Michiel Vanhoutte had a tuition fellowship from the Belgian American Educational Foundation.

George C. Whitfield is a recipient of an Intel Foundation 2007–08 Fellowship.

The BioVolt Team, Ethan Crumlin, Gerardo Jose la O', Joe Walish (graduate students), John Craven, and Andrew Hoy (juniors) placed third at the Global Social Venture Competition. BioVolt, the MADMEC first-place winners in 2007, uses biomass to generate energy and has developed a handheld device that stores this energy for applications like powering cell phones. This concept is of particular interest in rural areas where electricity can be scarce.

New Faculty Chair Appointments

Francesco Stellacci will be named Paul M. Cook career development professor of materials science and engineering effective July 1. Alfredo Alexander-Katz will hold the Toyota career development professorship. Geoffrey Beach will hold the AMAX career development professorship. Michael J. Demkowicz will hold the John C. Chipman career development professorship.

Future Plans

We continue to work toward providing fellowships to all first-year graduate students. A new fellowship named for our colleague Anne Mayes was established with discretionary funds allocated from Professor Mayes, generously supported by her MIT friends and colleagues, and matched by the offices of the Dean of Engineering and the Provost. We have been the grateful recipients of gifts from Professor Mayes' colleagues and students, and we are delighted that a one-semester fellowship will be awarded to incoming student Dahyun Oh this fall. We will continue fund raising in hopes of funding a two-semester fellowship in the future.

Other priorities include fund-raising for purchases of further rapid-prototyping equipment and support and maintenance of the newly purchased equipment and renovation of lab and office space for three new junior faculty.

We are excited that several young alumni/ae have joined to form a DMSE Alumni Club that will serve as a resource to connect students with mentors, provide research opportunities or facilities, and create a means of communication between the alumni and our department.

Edwin L. Thomas
Department Head
Morris Cohen Professor of Materials Science and Engineering

More information about the Department of Materials Science and Engineering can be found at http://dmse.mit.edu/.