Department of Materials Science and Engineering

The Department of Materials Science and Engineering (DMSE) is in the midst of exciting innovations and transitions. As the Physics, DMSE, Spectroscopy, and Infrastructure (PDSI) construction project has begun, departmental headquarters and some faculty, staff, and student offices have relocated temporarily, and all are excited about the new and more effective spaces that will result from these renovations. A search committee for the new department head has been formed, and it is expected that they will make a recommendation to the dean early in the fall semester. We have maintained our strong reputation for academic excellence, and our graduate program was again ranked top in the nation by *U.S. News and World Report*.

The death of Professor Morris Cohen in May marked the end of an era in DMSE's history. We were deeply saddened by the loss of this educator, friend, and leader in our field. Professor Cohen received the SB and the ScD in metallurgy from MIT in 1933 and 1936, respectively. He joined our faculty in 1936 and remained active long past his retirement in 1987. In 1974 he was named an Institute Professor. He received dozens of awards and honors, including the National Medal of Science and the Kyoto Prize for Advanced Technology. His research led to deeper understanding of steel and titanium-based alloys and, as a result, he was asked to serve on many panels and committees, including the National Aeronautics and Space Administration Advisory Council, the National Materials Advisory Board, as a consultant to the Atomic Energy Commission and the Department of Defense, and as deputy director of the Manhattan Project at MIT. In our field, he is most well known for the National Academy's Committee on the Survey of Materials Science report "Materials and Man's Needs," which led to the integration of the separate disciplines in materials science and engineering. A memorial service will be held on campus during the coming academic year.

Professor Michael Cima has led the effort to draft a strategic planning document for the department. Many faculty and staff provided input to articulate our goals, address current threats or weaknesses, and consider new opportunities for our discipline. This plan provides an invaluable resource and will be carefully considered as the department makes the transition to new leadership.

Research Initiatives

In September 2005, the second phase of the Singapore–MIT Alliance (SMA) will begin, and DMSE will continue to be a large part of this initiative. Our faculty continue to participate in other major MIT initiatives, such as the Institute for Soldier Nanotechnology, the Deshpande Center for Innovation, and the DuPont–MIT Alliance.

Undergraduate Education

DMSE's undergraduate enrollment stands at about 128 students and currently includes 52 percent women, 4.7 percent underrepresented minorities, and 2.3 percent international students. The department undergraduate recruiting efforts include participation in Academic Expo during freshman orientation, an open house, the semiannual John Wulff Lectures, direct mailings to the freshman class, freshman

advising seminars, and IAP activities. The Internship Program continues to attract the majority of DMSE undergraduates; 45 DMSE rising seniors and juniors are working at 32 host institutions at 33 locations for the summer of 2005, including 7 overseas institutions.

After five years as an experimental program, the SB in Archaeology and Materials (3-C) is now a permanent major. The Committee on the Undergraduate Program reviewed the 3-C degree in AY2004 and endorsed it, citing its merging of social sciences, humanities, science, and engineering as an example of collaborative, interdisciplinary programs it wishes to encourage.

Graduate Education

The department has a very healthy graduate student enrollment, numbering 221 in fall 2004. Approximately 30 percent of the graduate students are women and 1 percent are underrepresented minorities. Fourteen students were enrolled in the Program for Polymer Science and Technology, 12 students were jointly enrolled in DMSE and in the Leaders for Manufacturing Program, and 6 were jointly enrolled in DMSE and in the Health Science and Technology Program. For the fall of 2005, a total graduate student enrollment of about 247 is anticipated, approaching the largest DMSE graduate enrollment. An incoming class of 70 is expected, 41 percent of whom are domestic.

Our Master of Engineering (MEng) program is in its fourth year. A class of 13 students will graduate in September 2005 and we will welcome a new class of 24 students in the coming academic year. The significant rise in enrollment is largely the result of new fellowship support that is provided by SMA.

Student Organizations

Officers of the Society of Undergraduate Materials Scientists for AY2006 will be Kimberly Kam, president; Louise Giam, vice president; Jane Yoon, secretary; and Sally Lou, treasurer.

The Graduate Materials Council (GMC) officers for AY2006 will be Andrew Detor, president; Brian Hohmann, vice president; Treasurer, Tim Chin, treasurer; and Gabby Gaustad, academic resources. Representatives to the Departmental Committee on Graduate Students will be Elisa Alonso and Asher Sinensky. Graduate Student Council representatives will be Pedja Djuranovic, Suelin Chen, and Gagan Sanai; social chairs will be Jay Trelewicz, Binu Oomen, Biraja Kanungo, Trey Holzwarth, and Federico Villalpando; and intramural chair will be Rick Rajter.

Personnel

Dr. Stephanie Reich of Cambridge University has formally accepted our offer to join us as an assistant professor of materials science and engineering and will officially join the department on October 1. Dr. Reich is presently an Oppenheimer fellow at Cambridge University with active research projects in the areas of carbon nanotubes and Raman spectroscopy.

Professor John Vander Sande, Cecil and Ida Green distinguished professor, retired this June after a career spanning 30 years at MIT. In addition to his teaching and research in our department, he served as associate dean of the School of Engineering from 1992 to 1999, during which time he twice served as acting dean. He played an active role during the inception stages of MIT's global initiatives, SMA and the Cambridge–MIT Institute (CMI). He was also the first executive director of CMI. DMSE and MIT are deeply grateful for his years of dedicated and enthusiastic service.

Effective July 1, 2005, Professor Angela Belcher will be promoted to professor (with dual appointments in DMSE and the Biological Engineering Division), as will Professor Ron Ballinger (dual appointments in DMSE and Nuclear Engineering). Professors Yoel Fink, Nicola Marzari, and Chris Schuh will be promoted to the rank of associate professor without tenure.

Professor Lorna Gibson became chair of the Faculty effective June 15.

Research Highlights

A powder-metallurgy process for making geometrically complex tool steel parts via three-dimensional printing or related solid-freeform fabrication processes has been demonstrated by Professor Allen's group through fabricating a part of D2 tool steel composition.

Professor Belcher has focused on the rapid and effective identification of biological-inorganic combinations using combinatorial peptide evolution that will form the building blocks of bioelectronic devices.

Professor Carter's research focuses on predicting macroscopic properties that derive from materials' microstructures and on creating the required theoretical infrastructure for materials behavior to understand and engineer materials. Topics of recent papers and theses include extending microstructural models to account for variable crystal orientation and the effects of interfacial energy anisotropy on the structure of nanoparticles attached to interfaces.

Professor Ceder's group demonstrated that the standard ab-initio approach commonly used to perform first-principles calculations on solids creates significant errors in predicting the energy of redox processes due to the lack of self-interaction cancellation as electrons are transferred between environments. They showed how to correct it with fully ab-initio implementations of the DFT+U approach, which significantly enhances the capability of accurately predicting the potentials at which redox reactions occur.

Professor Chiang initiated a new program supported by the Defense Advanced Research Projects Agency, Electrochemically Actuated Nastic Structures, aimed at developing materials and active structures that enable the morphing of air vehicles, as well as a new US Army–sponsored program aimed at developing new materials for ultrahigh-energy density rechargeable lithium batteries.

In Professor Cima's laboratory, measurements have been taken that reveal the dependence of the behavior of inorganic aqueous interfaces on surface structure. It was observed that three sapphire surfaces exhibit strikingly different degrees of acidity. A structural basis for the relative differences between the surfaces was proposed.

Professor Clark developed a methodology for extending engineering models to calculate a "life-cycle emissions inventory" based on a robust understanding of the engineering processes involved.

Under the supervision of Professor Eagar, the MIT Welding and Joining Group is developing a process to allow in situ skinning of large, complex metallic foam parts that will be very useful in repair applications.

A medical device based on a photonic bandgap fiber developed by Professor Fink's group is currently awaiting FDA approval for noninvasive laser treatment of tumors in the larynx and lungs. Fabrics containing photonic bandgap yarns pioneered by this group are under consideration for use in a US military optical identification system.

Professor Fitzgerald demonstrated a variety of engineered substrates for novel device and system applications: strained Si on Si, thin relaxed SiGe on Si, Ge on insulator on Si, and III-V on insulator on Si. His group also discovered that tensile strained films can getter [[Is this verb correct?]] H very efficiently, leading to controlled splitting of layers at much lower dose or temperature than traditional ion-cut techniques.

Professor Gibson continues a collaboration with Cambridge University on the development of scaffolds for bone and cartilage tissue engineering. Her group submitted a technology disclosure on the processing of scaffolds in these applications and is working to submit a patent application in the UK.

Professor Hosler continued a program of excavation at El Manchón, in the state of Guerrero, Mexico, the only known ancient copper-smelting site in Mesoamerica. This group has collected a large volume of pottery, as well as metallurgical and architectural data, and is in the process of making laboratory studies of these materials.

Using a novel photoresist and lithographic strategy developed in his lab, Professor Irvine demonstrated for the first time the immobilization of two proteins into different regions of a substrate without exposure of either biomacromolecule to any condition except their native physiologic aqueous buffer conditions. This approach may be generalized to patterning any number of proteins on a surface.

Professor Kimerling's research demonstrated photonic-crystal texturing of silicon solar cells for enhanced optical path length.

Professor Lechtman is engaged in a long-term investigation of the bronze technologies that developed in the Andean zone of South America during the prehistoric period. Current research focuses on determining the rare ore source for the nickel component of a ternary Cu-As-Ni bronze.

Professor Marzari's research group characterized organic functionalizations in carbon nanotubes and identified ligands that induce an opening and a closing in the ballistic conduction as a function of applied electric fields or chemical potentials, opening the way to nanotube-based sensors and memories.

Professor Mayes has fabricated nanocomposites by growing continuous transition metal oxide phases within ion-conducting domains of a block copolymer electrolyte template and demonstrated their use as lithium rechargeable battery cathodes.

The research in Dr. O'Handley's group, mainly in ferromagnetic shape-memory alloys, is supported by a five-year Multi-University Research Initiative grant. This collaborative work includes MIT professors Samuel Allen and Yet-Ming Chiang of DMSE and Professor Steven Hall of Aeronautics and Astronautics. This team discovered a new phenomenon in which the large magnetic field–induced strain in Ni-Mn-Ga is significantly enhanced by the simultaneous application of a small acoustic signal to the crystal.

Professor Ortiz investigated the surface properties of hydroxyapatite, one of the most promising ceramic bone implant materials, and for the first time quantified and mapped the nanoscale spatial variation in surface forces and surface charge per unit area within and across individual polycrystalline grains and grain boundaries.

Dr. Paul studies the time-dependent model of variant (or grain) growth by twin-boundary motion, including discrete lattice effects, twin-boundary–dislocation interactions, viscosity, and externally induced acoustical vibrations in the presence of directed external driving forces.

Professor Powell's group reached important milestones in phase-field modeling, including simulations of polymer membrane structure formation and incorporating fluid-structure interactions. The first detailed model of electrochemical dendrite formation was presented and extended to simulate shape changes during electronically mediated reactions.

Professor Ross conducted research into the phase separation in thin films of block copolymers to generate nanolithography templates for making large-area arrays of magnetic dots. A paper in *Nature Materials* describes and models the pattern formation in confined geometries.

Professor Roylance's research centers on process-structure-property investigations of polymers and composite materials, dealing especially with mechanical properties including the durability of filled elastomers subjected to large cyclic loads and the role of chain extension versus crosslinking in high-temperature polymer matrix resins.

Professor Russell studies the structure and properties of displacement cascades as they pertain to theories for nucleation of voids and precipitate particles. Cascade-related effects on nucleation are highly relevant to current and proposed nuclear reactors for electrical power generation.

Professor Sadoway designed, synthesized, and tested a single-ion solid polymer electrolyte that offers improved performance in a thin-film solid-state battery.

Professor Schuh's research focuses on the development and properties of nanostructured materials, which have a very high density of interfaces. His group recently disclosed a technique to tailor the grain size of Ni-W alloys to any desired value over 2–50 nm based on electrodisposition and to produce large plates of fully nanostructured alloy in the laboratory.

Professor Stellacci published the discovery of the first nanostructured nanomaterial class: metal nanoparticles coated with a mixture of phase-separated molecules. This discovery demonstrates that phase separation exists on a length scale never before observed or predicted.

Professor Suresh's recent research has dealt with nanoscale mechanical response of thin films and fine-grained materials, as well as cellular and subcellular mechanics with applications to human diseases such as malaria and pancreatic cancer.

Professor Thomas' group has begun to study phononic crystals, the sound analog of photonic crystals.

Professor Thompson's group has made highly sensitive stress measurements during intermittent ultrahigh vacuum growth of thin films, demonstrating that stress measurement can be used as an in situ and real-time probe of surface structure evolution during film growth, providing a new route to investigate and control thin-film structure evolution.

Professor Van Vliet is studying the effects of substrate stiffness on endothelial cells. Preliminary results indicate that cells generally attach and proliferate preferentially on the most mechanically stiff substrate available but that the extent to which this mechanical transduction is active depends on cell type and donor.

Professor Wuensch has explained the evolution of disorder in perovskites with change in composition through application of bond-valence summations.

Professor Yip's group has studied the influence of stress on the activation energy barrier in the reaction between a water molecule and a silica nanorod, with implications for stress corrosion cracking and hydrolytic weakening of quartz.

Awards and Honors

The GMC presented the Outstanding Graduate Teaching Award to Professor Sam Allen; the GMC Outstanding Advisor Award was presented to Professor Chris Schuh.

One of the 2004 MacArthur Fellowship recipients is Professor Angela Belcher; the five-year award for $500,000 is commonly known as a "genius grant." Professor Belcher is recognized for her groundbreaking work in "developing new techniques for manipulating systems that straddle the boundary of organic and inorganic chemistry

at the molecular scale." Professor Belcher also received a four-star recognition award for "significant contributions to Army Transformation." The *Mass High Tech* newsletter has recognized Professor Belcher as one of the "Women to Watch." This annual list spotlights innovators who will "shape the future" and serve as role models for girls interested in science and engineering.

At the 2005 annual meeting of the American Ceramic Society (ACerS), Professor Craig Carter was presented the Richard M. Fulrath Award, which recognizes outstanding academic and industrial ceramic engineers/scientists. The awardees participate in the Fulrath Symposium at the annual meeting and then present a paper at the annual meeting of the Ceramic Society of Japan.

Professor Yoel Fink has received the National Academy of Sciences (NAS) Award for Initiatives in Research—a prize of $15,000 awarded annually in a field supporting information technology (condensed matter/materials science in 2004) to recognize innovative young scientists and to encourage research likely to lead toward new capabilities for human benefit. He was chosen "for his pioneering contributions and ingenuity in the creative design and development of photonic materials and devices."

Professor Darrell Irvine was named one of *Technology Review*'s TR100 for 2004. The TR100 recognizes the top young innovators in technology in a given year.

Professor Ross was elected fellow of the American Physical Society for her "innovative research into the magnetic properties of thin film and nanoscale structures, and for the development of novel lithographic and self-assembly methods for nanostructure fabrication."

Professor Schuh received the Presidential Early Career Award in Science and Engineering at a ceremony at the White House last fall. He was nominated by the Department of Defense based on work he has done at MIT for the Army Research Office.

At the American Society of Materials International annual meeting, Professor Suresh was awarded the 2004 Albert Sauveur Achievement Award. The award recognizes his "outstanding contributions to the understanding of deformation behavior at different length scales and mechanics of materials and demonstrated leadership in materials education." The Sauveur Award is named for an early alumnus of our department. In December, Professor Suresh was elected to the Third World Academy of Sciences. He is recognized for his "broad, innovative and pioneering contributions to the area of mechanical properties of materials," which "has led to the understanding of these properties from the atomistic to the continuum levels." Professor Suresh was also elected an honorary ellow of the Indian Academy of Sciences.

Mindy Baughman was a recipient of a 2004/2005 MIT Excellence Award for her participation on the Artists Behind the Desk Committee.

In May, School of Engineering Infinite Mile Awards were presented to Esther Greaves Estwick, personnel officer in the Administrative Services Office, and to Peter Houk, director of the Glass Lab.

Undergraduate Awards

Anna Bershteyn's Solar Water Disinfection Device team was a winner in the 2005 IDEAS competition. Ms. Bershteyn was also named Outstanding Junior, DMSE Class of 2006. Catarina Bjelkengren was one of the participants and organizers of the 8th annual MIT $50K GSW Conference in Abu Dhabi, United Arab Emirates. Nduka Enemchukwu received one of the Ronald E. McNair Scholarship Awards. Julie Goss received the Star Volunteer Award for three years of work on the IDEAS competition. Ms. Goss also received the DMSE award for Outstanding Senior Thesis. Jiji Gu received honorable mention in the Boit Manuscript Prize for her essay from MIT's Program in Writing and Humanistic Studies. Elizabeth Hager was named Outstanding Student, DMSE Class of 2005. Elizabeth Hager, Joanna Natsios, and Peter Stone received certificates of honor for their perfect 5.0 Cumulative GPA. Anita Krix received honorable mention for the Robert A. Boit Writing Prize for her short story from MIT's Program in Writing and Humanistic Studies. Kevin McComber was recognized for his outstanding service to the DMSE community. Kevin McComber, David Schoen, and Peter Stone were all named to Phi Beta Kappa. Christopher Ng received the award for Best 3B Internship Report. Grady Snyder and other members of the MIT swim team qualified to compete in the NCAA Division III Swimming and Diving Championships held in Holland, MI, in March; the MIT team was ranked 10th in the nation. Irene Tobias was named Outstanding Sophomore, DMSE Class of 2007. Elizabeth Zellner received 2nd prize for "Writing Science Fiction" from MIT's Program in Writing and Humanistic Studies.

Graduate Awards

Four MIT graduate students were recognized as medal winners at the Materials Research Society (MRS) fall meeting in Boston: Ion Bita of DMSE (silver medal), Delphine Dean of Electrical Engineering and Computer Science (gold medal), Jifeng Liu of DMSE (gold medal), and Daniel Solis of Chemistry (silver medal). Delphine Dean works with Professor Christine Ortiz and Daniel Solis works with Professor Angela Belcher.

John Mills and his coauthors received a Ribbon Award for their paper, "Continuous Force-Displacement Relationships for the Human Red Blood Cell at Different Erythrocytic Developmental Stages of *Plasmodium falciparum* Malaria Parasite," presented at the December 2004 MRS meeting in Boston. The paper will be published in the *Proceedings of the Materials Research Society.*

For his talk entitled "Phase Field Modeling of Grain Boundary Transitions," Ming Tang was named a Diamond Award winner for the ACerS Graduate Excellence in Materials Science. This award, established by the Basic Science Division and presented for the first time at the 2005 annual meeting, recognizes students for their academic and scientific accomplishments, as well as for the research they present at the conference. Mr. Tang is an advisee of professors Yet-Ming Chiang and Craig Carter.

Kathleen Huffman received the Elsevier Outstanding Graduate Student Prize. Wanida Pongsaksawad received the John Wulff Award for Excellence in Teaching.

Faculty Chairs

Faculty members of this department included these chairholders during the 2005 academic year: Samuel Miller Allen, POSCO professor of physical metallurgy; Angela Belcher, John Chipman career development associate professor of materials science and engineering and biological engineering; W. Craig Carter, Lord Foundation professor of materials science and engineering; Gerdbrand Ceder, R. P. Simmons professor of materials science and engineering; Yet-Ming Chiang, Kyocera professor of ceramics; Michael Cima, Sumitomo Electric Industries professor of engineering; Thomas W. Eagar, Lord Foundation professor of materials engineering and materials systems; Yoel Fink, Thomas B. King assistant professor of materials science; Eugene A. Fitzgerald, Merton C. Flemings–SMA professor of materials engineering; Merton C. Flemings, Toyota professor emeritus of materials processing; Lorna J. Gibson, Matoula S. Salapatas professor of materials science and engineering; Darrell J. Irvine, Karl Van Tassel assistant professor of biomedical engineering and materials science and engineering; Klavs Jensen, Lammot du Pont professor of chemical engineering and materials science and engineering; Lionel C. Kimerling, Thomas Lord professor of materials science and engineering; Nicola Marzari, AMAX career development assistant professor of materials engineering; Anne M. Mayes, Toyota professor of materials science and engineering; Caroline A. Ross, Merton C. Flemings career development professor of materials science and engineering; Michael Francis Rubner, TDK professor of materials science and engineering; Donald Robert Sadoway, John F. Elliott professor of materials chemistry; Christopher Schuh, Danae and Vasilos Salapatas assistant professor of metallurgy; Francesco Stellacci, Finmeccanica assistant professor of materials science and engineering; Subra Suresh, Ford professor of engineering; Edwin L. Thomas, Morris Cohen professor of materials science and engineering; Carl V. Thompson, Stavros Salapatas professor of materials science and engineering; and John Vander Sande, Cecil and Ida Green distinguished professor of materials science and engineering.

Future Plans

The final phase of the major undergraduate curriculum revision will be completed in fall 2005 with the introduction of the new senior year curriculum. The integrated educational experience of our “new” undergraduate program will continue to expand with the addition of new elective options for seniors in AY2006. We hope that the success of this program will help us achieve our goal of reaching the School of Engineering average undergraduate student/faculty ratio (4.8). We will make a concerted fund-raising effort to raise first-year graduate fellowship support to a level where most if not all first-year students are supported on a fellowship.

Each of our standing departmental committees will have diversity tasks to increase the number of underrepresented minorities in both faculty and students. As our graduates report that they have followed careers in medical device, biotech, and pharmaceutical industries, we see the need for a biomedical materials track in our undergraduate curriculum. We will continue to build world-class research facilities in order to attract a high caliber of faculty.

Subra Suresh
Department Head
Ford Professor of Engineering

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