Department of Materials Science and Engineering

The Department of Materials Science and Engineering (DMSE) continues to thrive as its faculty and students are producing research that changes the way materials are made and used, thereby providing new solutions to some of the world's biggest challenges in energy, transportation, and medicine. In 2009, U.S. News and World Report named both the DMSE undergraduate and graduate programs best in the nation; while thrilled to have achieved this honor, the department has begun a concentrated reevaluation of its academic programs, aiming to provide the best education possible in a rapidly evolving field and to meet the needs of increased undergraduate and graduate enrollments.

Construction of the Laboratory for Advanced Materials (LAM) was completed in December 2009 and the lab was officially opened in March 2010. This lab provides shared facilities for DMSE researchers to pursue joint projects in interdisciplinary areas. The LAM's characterization and processing equipment complements recent acquisitions in other MIT labs and centers and enables research groups to work together on new materials and processes for cross-cutting applications in challenging areas such as energy and the environment. This facility features some of the most advanced materials experimentation equipment on the MIT campus, including a scanning acoustic microscope, a nearfield scanning optical microscope, a cryogenic four-point probe station, and equipment for photolithographic patterning at the nano- and microscales. Architecturally, the open space encourages shared interactions, inside the lab and with the MIT community. The design of the renovated spaces allows for future technical developments through the use of rolling benches and movable point chemical exhaust trunks and by incorporating power and utilities into ceiling tracks. The patterns set in the floor tiles depict the 17 two-dimensional plane symmetry groups.

The LAM is funded by a generous gift from Vasilios, SM '61, PhD '66, and Danae Salapatas. The retired managing director of Helliniki Halyvourgia, the first steel plant in Greece (started in 1938 and still one of the largest industrial plants in the country), Dr. Salapatas is an active member of the DMSE alumni community, a member of the DMSE visiting committee, and a generous benefactor and supporter of MIT.

Now in its fourth year, the Making and Designing Materials Engineering Contest (MADMEC) continues to produce innovative ideas while providing students with an opportunity to explore the DMSE prototyping facilities. Thermeleon's color-changing roof tiles, the 2009 winners, have appeared on many online news sites as well as in the Cooper-Hewitt Museum of Design. Financial support for MADMEC is currently provided by Saint-Gobain, Dow Corporation, and BP. Student teams are designing and prototyping devices that harness, store, or exploit sources of alternative energy through principles of materials science and engineering for a top prize of $10,000, to be awarded this fall. They are receiving mentoring advice from engineers at Saint-Gobain's Research and Development Center in Northboro, MA.

Research Initiatives

Research volume has increased again this year. In its fourth round of seed grants supporting innovative, early-stage research, the MIT Energy Initiative awarded funding to professors Yoel Fink, Silvija Gradečak, Jeffrey Grossman, Yang Shao-Horn, Edwin L. Thomas, Carl V. Thompson, and Harry Tuller. Professor Donald R. Sadoway and his group are recipients of Department of Energy funding for developing clean-energy technology through liquid metal batteries. BP has provided a grant of $1,000,000 per year for five years to enhance research relevant to materials for oil field production and exploration. This initiative involves faculty from DMSE and Nuclear Science and Engineering. On the international front, the National Science Foundation is funding a joint project between MIT and the University of Bayreuth to study catalysts, with the aim of further reducing automotive emissions; professor Harry Tuller is the primary investigator at MIT.

Undergraduate Education

The incoming sophomore class of 50 students brings DMSE's undergraduate enrollment to 141 students (a 35.6% increase from last year), with 59% women, 35% underrepresented minorities, and 3.5% international students. Twenty-one students are designated Course 3-A (a flexible degree program often taken by students intending to study medicine, business, or law), and one student is designated Course 3-C (archaeological materials science). The internship program continues to attract many DMSE undergraduates; 43 DMSE rising seniors and juniors are working at 34 host institutions for summer 2010, including 11 overseas institutions.

The department is assessing our undergraduate curriculum, last revised in AY2003, to ensure that it prepares students for further academic study or for careers in such diverse areas as traditional industry, start-up companies, and government.

In September 2009, DMSE participated for the first time in MIT's Freshman Pre-Orientation program (FPOP). "Discover Materials Science and Engineering" provided a glimpse into the past, present, and future of materials science and engineering. The program, organized by current graduate student Siamrut Patanavanich, '08, allowed 18 freshmen to spend three days exploring MIT and Boston, as seen through an often unconventional perspective of materials science and engineering. This program, to be offered again in 2010, joins DMSE's other opportunities for first-year students: 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 activities.

Graduate Education

The department's graduate enrollment remains healthy, numbering 221 in fall 2009. Approximately 28% of the graduate students are women and 4.5% are underrepresented minorities. Fifteen DMSE students participate in the Program in Polymer Science and Technology. For fall 2010, we anticipate an incoming class of 59, approximately 43% of whom are domestic students.

The department has decided to no longer offer the master of engineering degree after an assessment was conducted by committee this past academic year. In addition, the department will no longer participate in the dual master's degree program with the Sloan Leaders for Global Operations. Professor Christopher Schuh will chair the department committee on graduate students as they reevaluate the current master of science degree program this upcoming academic year.

Student Organizations

The officers of the Society of Undergraduate Materials Scientists for 2010–2011 will be Kathy Bui and Brienne Kugler, copresidents; Jamie Huang and Tara Sarathi, social chairs; Bethany Tomerlin, career development chair; Tiffany Mickel, recruitment chair; Ester Lomeli and Elizabeth O'Gorman, publicity chairs; Garrett Lau, secretary/historian; Kirsten Hessler, lounge/FPOP chair; and Daniel Sauza and Miranda Amarante, general board members.

The Graduate Materials Council officers for 2010–2011 will be William Woodford, president; Satoru Emori, vice president; Vivek Singh, secretary; Salvador Barriga, treasurer; Richard Baumer and Jordan Chesin, academic committee; Adam Jandl, Jocelyn Newhouse, Daniel Harris, and Siamrut Patanavanich, social chairs; Jon Singer, Nick Thompson, and Neil Patel, representatives to the departmental committee on graduate students; Ahmed Al-Obeidi, publicity chair; Reid Van Lehn, athletics chair; Eric Jones, outreach chair; Kevin Gotrik, Charles Sing, and Adam Hannon, alumni relations committee; and Max Solar, Rodolfo Camacho, and Sophie Ni, Graduate Student Council representatives.

These student organizations are invaluable resources, acting as departmental ambassadors to prospective undergraduates and graduate students.

Personnel

Effective July 1, 2010, professor Christine Ortiz will be promoted to full professor. Professor Ortiz joined the MIT faculty in 2000, after receiving the BS from Rensselaer Polytechnic Institute (1992) and the MS and PhD from Cornell University (1997). Starting in fall 2010, Professor Ortiz will be the dean for graduate education.

Professor Francesco Stellacci has left the Institute to take a position at the Swiss Federal Institute of Technology.

Professor Samuel M. Allen will become chair-elect of the MIT Faculty in AY2011.

Joseph M. Dhosi, internship coordinator and former DMSE administrative officer (AO), retired on June 30, 2010. Mr. Dhosi holds the SM from Course III (1959) and began working as the AO in 1976. His deep affection for students and generosity toward all he worked with will be remembered.

Yin-Lin Xie, technical instructor, has retired after 25 years in DMSE. Ms. Xie assisted faculty and students with metallography, mechanical testing, and heat treatment.

Undergraduates have known her as a member of the teaching staff for 3.081, 3.082, and 3.042, while graduate students have benefited from her advice on their thesis experimentation.

Research Highlights

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

Over the past year, professor Alfredo Alexander-Katz's group has published several high-impact research accomplishments, some of which have seen extensive media coverage in venues such as *MIT News* and *EurekAlert*. A major accomplishment was the creation of self-assembled microscopic surface walkers, the so-called micro-ants. As these assemblies walk on surfaces, they drag the surrounding fluid with them, thereby gaining the ability to "carry" much bigger objects. The Alexander-Katz group demonstrated full control of the motion of artificial cells using these dynamic self-assembled materials and explained all their properties theoretically, paving a route for future experimental and theoretical developments in this area. This work was accepted for publication in *Proceedings of the National Academy of Sciences*.

Another project showed for the first time that internal friction occurs in collapsed polymers, another key area of research of the Alexander-Katz group. This research has consequences in the area of protein folding and unfolding as well as in protein conformational changes. This work, published in *Physical Review Letters*, is important for understanding how certain proteins unravel in blood flow. They have also shown for the first time that elongational flows may play a crucial role in catalyzing self-healing reactions such as blood clotting; the work has been accepted for publication in *Biophysical Journal* (Communications). In another area, Professor Alexander-Katz is collaborating with professor Caroline Ross to show theoretically and experimentally that graphoepitaxy can be used to assemble large complex patterns with block copolymers, a work that will appear in *Nature Nanotechnology*.

Professor Geoffrey Beach's group studies spin dynamics in nanoscale magnetic materials and devices. In the past year, they have focused on magnetic domain wall motion in thin-film nanowire structures with applications in low-power solid-state magnetic data storage and novel biomedical devices. A sequence of magnetic domain walls along a ferromagnetic nanowire can be used to encode information. The domain walls can be transported simply by passing a current through the wire because of the torque applied by the spin of the moving conduction electrons. This interaction can be used to electrically control magnetic data without the need for high-power external magnetic fields. In most materials, the current density required to displace magnetic domain walls is so large that heating and electromigration can destroy the device. Micromagnetic simulations developed by Professor Beach's group indicate that the threshold for current-induced domain wall motion can be dramatically reduced by tuning the material anisotropy to compensate the magnetostatic energy barrier that separates stable domain states. They are studying this effect by using heterostructures of several atomic layers of cobalt sandwiched between thin nonmagnetic platinum layers. Experiments are under way using a unique scanning magnetooptical microscope with extremely high spatial and time resolution, which was built over the past year by students in the Beach group.

In related work, Professor Beach's group has developed magnetic nanowire-based circuits that can be used to physically transport functionalized magnetic nanoparticles across the surface of a chip for applications in nanomedicine and pathogen detection. The stray magnetic field near a domain wall acts as a magnetostatic trap that can bind and pull along magnetic nanoparticles in a fluid suspension. A patterned magnetic nanowire structure on a chip can be used as a conduit to transport magnetic nanoparticles with chemically tethered biological or chemical cargo. Professor Beach's group has recently demonstrated the controlled parallel transport of multiple particles by a magnetic domain wall "conveyor belt" fabricated on a silicon wafer, in which a train of magnetic domain walls can be driven in unison with an externally applied rotating magnetic field. Their recent calculations suggest that these devices should support extremely fast transport of individual particles through a fluid, up to 10 mm/s, or several orders of magnitude faster than conventional magnetophoretic motion. The possibility of such fast, long-distance transport with microscale control may enable a new generation of cheap, sensitive, high-throughput chip-based medical diagnostic technologies.

Professor Michael Demkowicz and his group have conducted detailed studies of the mechanisms of point defect interactions and metal–metal heterophase interfaces. They found that trapping and transport of point defects can be quantitatively described by using the configuration of interface misfit dislocations, which in turn can be predicted based on dislocation dynamics modeling. This work opens the prospect of developing strategies for the atomic-scale design of new classes of composite materials tailored for service in extreme environments—for example, under irradiation, severe plastic deformation, or shock loading or in corrosive media.

The Demkowicz group collaborates with Los Alamos and Lawrence Livermore National Laboratory to investigate the fundamental physics of defect creation in irradiated amorphous alloys and, for the first time, He-implanted nanocomposites. The group is also actively involved in the conceptualization of next-generation user facilities whose goal will be to investigate experimentally the predictions of atomistic simulations at nanometer-length scales and picosecond time scales.

Professor Jeffrey Grossman, who joined DMSE last fall, develops and applies a range of computational materials science tools to predict new materials with improved properties. His group applies these techniques to applications primarily focused on energy materials, including solar photovoltaics, thermoelectrics, hydrogen storage, and solar fuels, while concomitantly exploring fundamental limits in the key material properties involved, such as light-matter interactions, heat transport, and the assembly of nanostructures. During this past year, Professor Grossman worked with professor Tonio Buonassisi (Mechanical Engineering) to theoretically and experimentally probe the effects of pressure on hole mobility on amorphous silicon solar cells. Their simulations predict that 2D pressure may allow the holes to become "untrapped" while 1D or 3D pressure is ineffective. Also in the area of solar photovoltaics, Professor Grossman recently developed a simulation approach to optimize the 3D structure of a solar cell based on genetic algorithms. Together with his first graduate student at MIT, he published an article in *Applied Physics Letters* on the topic. With professors Vladimir Bulovic and David Perreault (Electrical Engineering and Computer Science), he is

building prototypes and has recently joined forces with an Italian energy company (Enel) to further explore, refine, and test the concept of 3D photovoltaics.
Related to thermoelectrics at the fundamental level is the flow and dissipation of heat. In this area, Professor Grossman has also recently made an important contribution; his team simulated the nature of intrinsic heat dissipation in carbon nanotubes. Quite surprisingly, as they showed in their article in *Nanoletters*, heat in such materials dissipates in a highly frequency-dependent manner, leading to anomalous drops in the quality factory by two orders of magnitude and behavior that is quite similar to the "Mpemba Effect," in which hot water can cool faster than cold water under certain conditions.

Awards and Honors

MIT's Committee on Race and Diversity presented professor Samuel M. Allen with a mentoring award.

Professor Angela Belcher received the 2010 University of Alabama at Birmingham Ireland Distinguished Visiting Scholar Award.

At the Materials Research Society (MRS) fall meeting, professor Gerbrand Ceder received the MRS Medal.

Professor Yet-Ming Chiang was named an MRS fellow, was named one of *Forbes Magazine*'s "Most Powerful Innovators," and received the American Ceramic Society 2009 Corporate Technical Achievement Award in recognition of his outstanding achievement in the field of ceramics, particularly in founding A123 Systems.

The Alfred P. Sloan Foundation named professor Jeffrey Grossman a research fellow.

Professor Randolph J. Kirchain, Jr., and MIT colleagues received the General Motors Charles L. McCuen Research and Development Innovation Award.

Professors Anne M. Mayes and Edwin L. Thomas were named founding POLY fellows, a new award made to fellows of the American Chemical Society Division of Polymer Chemistry.

The University of Illinois Materials Science and Engineering Alumni Board presented professor Christopher Schuh with its Distinguished Young Alumnus Award.

Professor Subra Suresh received an honorary doctorate from the Universidad Politécnica de Madrid. Professor Suresh received the Campbell Award from the American Society for Materials International.

Professor Carl V. Thompson received the Innovation Award from Semiconductor Research Corporation.

Professor Harry Tuller received the Electrochemical Society's High Temperature Materials Division Outstanding Achievement Award.

Professor Krystyn J. Van Vliet was selected to participate in the National Academy of Engineering's 15th annual U.S. Frontiers of Engineering symposium.

Kathy Simons, support staff member, received a School of Engineering Infinite Mile Award.

Undergraduate Awards

Ellen McIsaac received MIT's Edward L. Horton Fellowship Award for her work as a director of MIT's Career Fair.

The Horace A. Lubin Award for Outstanding Service to the DMSE Community was presented to Siamrut Patanavanich.

The Best Internship Report was awarded to Thomas W. Hay for "Electrical Characteristics of Femto-second Laser Microstructured Silicon Photodiodes"; the recipient of the Outstanding Senior Thesis Award was Mihai Duduţă for "Semi-solid Rechargeable Flow Battery."

The awards for outstanding senior, Class of 2010, went to Bryn Waldwick. Recipients of the outstanding junior awards, Class of 2011, were Lina Garcia and Ian Matts. The outstanding sophomore, Class of 2012, was Joshua Steimel.

Bryn Waldwick was invited to join Phi Beta Kappa.

Mihai Duduţă was elected to Tau Beta Pi.

Graduate Awards

Tiffany Ziebell received the MRS/NSF ICMR Apprentice Science Reporter Award. In her role as a science writer, Ms. Ziebell composes short news stories based on pre-published materials research articles from peer-reviewed journals for the Research/Researchers feature of the *MRS Bulletin*.

Alfonso Reina was silver medal winner at the fall 2009 MRS meeting in Boston for his talk, "Single- and Few-layer Graphene Grown and Isolated from Ni Substrates."

Woochul Jung was a grand prize winner at the Samsung Electro-Mechanics Inside Edge International Thesis Competition.

Kevin McComber received MIT's Karl Taylor Compton Award in recognition of his devotion to the welfare of MIT and was also named "Chair of the Region of the Year" by the National Association of Graduate-Professional Students.

Yoda Patta was awarded MIT's Goodwin Medal, awarded to a teaching assistant in recognition of extraordinary and effective teaching.

Eric Homer received the Outstanding PhD Thesis Research Award for "Modeling the Mechanical Behavior of Amorphous Metals by Shear Transformation Zone Dynamics."

Uwe Bauer was recipient of the First-Year Graduate Student Exceptional Performance Award.

YongJoo Kim received the award for an outstanding paper by a first- or second-year graduate student for "Phase Behavior of Symmetric Disk-Coil Molecules."

The John Wulff Award for Excellence in Teaching was made to Salvador Barriga.

New Faculty Chair Appointments

Effective July 1, Angela Belcher will be the W.M. Keck professor of energy, Krystyn Van Vliet will hold the Paul M. Cook career development professorship, and Silvija Gradečak will be the Thomas Lord assistant professor of materials science and engineering.

Future Plans

It is very apparent that DMSE is healthy, vigorous, and helping provide important solutions to many of the world's toughest problems. We will soon announce the results of a search for a new assistant professor and are looking forward to our visiting committee review this coming October.

The growing societal awareness of the importance of both advances and shortcomings in the materials area is reinforced almost daily through news of innovations in battery materials, fuel cells, thermoelectrics, photovoltaics, fuels from sunlight, and so on as well as the dire consequences of materials failure such as the accidental explosion and sinking of the Deepwater Horizon drilling platform and the subsequent oil spill in the Gulf of Mexico and the accidental rupture of the main water conduit to Boston from the Quabbin reservoir. Researchers in our department are continually pushing the frontier with experimental observations at smaller and smaller length scales and at finer and finer time scales, providing necessary and vital input into computational models that can simulate and explain materials behavior in previously inaccessible regimes.

The department continues to address its primary challenges: keeping the laboratories up to date and maintaining state-of-the-art instrumentation and facilities. These objectives are critical due to our need to accommodate a rapidly increasing number of undergraduates as well as increased numbers of graduate students, postdocs, and visitors. The 14% increase in the research budget (and considerable additional funds coming in from the American Recovery and Reinvestment Act) helps us to meet these goals, while working creatively to manage the concurrent space, staffing, and time requirements.

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/.