

## **Department of Materials Science and Engineering**

The Department of Materials Science and Engineering (DMSE) finds itself at a transitional time of change and challenges, when research performed by our faculty and students is changing the world we live in, our undergraduate enrollment has increased significantly over the past few years, and new faculty bring exciting research directions to the MIT community. The increased enrollment demonstrates that students recognize our field's pertinence in addressing today's urgent needs in rechargeable energy sources, recycling, conservation, cancer treatments, drug delivery, and more, and new faculty skills and interests give us the opportunity to re-examine our curriculum. However, accommodating a larger student enrollment and housing new faculty requires a creative use of space, laboratory, and staffing resources—a challenge at any time but an even greater one today.

Construction began in June on the Laboratory for Advanced Materials (LAM) at the corner of Buildings 4 and 8 in the Infinite Corridor. The lab has been made possible by a generous gift from Vasilios and Danae Salapatas. Dr. Vasilios Salapatas holds an SM in chemical engineering (1961) and a PhD in metallurgy (1966), both from MIT.

Now in its third year, the Making and Designing Materials Engineering Contest has spawned patents and start-up companies. Financial support is currently provided by Dow Corporation and Saint Gobain, and Saint Gobain engineers provide mentoring advice to the nine student teams that 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 \$5,000, to be awarded this fall.

### **Undergraduate Education**

The growth of our incoming sophomore class to include 46 students is due in large measure to the extraordinary efforts of our students, staff, and faculty in sharing their belief that MSE can stand for “matter, sustainability, and energy.” DMSE's undergraduate enrollment stands at 104 students, with 50% women, 31% underrepresented minorities, and 2.8% international students. Eleven students are designated Course 3-A (a flexible degree program often taken by premed, business, or law students), and one student is designated Course 3-C (archaeological materials science). The internship program continues to attract many DMSE undergraduates; 33 DMSE rising seniors and juniors are working at 27 host institutions for summer 2009, including seven overseas institutions.

The department is assessing our undergraduate curriculum, last revised in AY2003, to ensure that it prepares students for fulfilling careers, whether in academia or in industry.

Later this summer, DMSE will offer a freshman pre-orientation program, “Discover Materials Science and Engineering,” to 20 incoming freshmen. This first-time offering 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 (IAP) activities.

Course 3.091 Introduction to Solid State Chemistry continues to be a great vehicle for sharing our field, not only within MIT but also outside. Last fall, Bill Gates was quoted in the *Seattle Post-Intelligencer* saying, “Everybody should watch chemistry lectures—they’re far better than you think. Don Sadoway, MIT—best chemistry lessons everywhere. Unbelievable.”

### **Graduate Education**

The department has a very healthy graduate student enrollment, numbering 211 in fall 2008. Approximately 32% of the graduate students are women and 4% are underrepresented minorities. The Program in Polymer Science and Technology has 18 enrolled students, three students are in the Leaders for Global Operations program, and four are currently in the Health Sciences and Technology program. For fall 2009, we anticipate an incoming class of 73, approximately 26% of whom are domestic students. We are delighted to have maintained our top ranking from *U.S. News and World Report*.

Now heading into its third year in AY2010, the teaching minor program has attracted several doctoral students who are completing the recommended 24-unit load, including Course 3.69 Teaching Fellows Seminar. Taught by professors Samuel Allen and Edwin (Ned) Thomas, this seminar helps prepare students 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 eighth year with 102 alumni. In September 2009, 12 students will graduate, and 22 students are expected to enroll in the upcoming academic year.

### **Student Organizations**

The officers of the Society of Undergraduate Materials Scientists for 2009–2010 will be Michele Lee, president; Daniel Sauza, social chair; Corey Kubber and Xavier Gonzalez, career development chairs; Patrick Ernst, recruiting chair; Jeffrey Disko, publicity chair and webmaster; and Leslie Nachbar, secretary.

The Graduate Materials Council officers for 2009–2010 will be Timothy Zens, president; Matthew Smith, vice president; George Whitfield, secretary; Salvador Barriga, treasurer; Richard Baumer, academic chair; Rodolfo Camacho, Hitesh Chelawat, Matthew Connors, Samuel Crawford, Satoru Emori, and Prithu Sharma, social chairs; Jon Singer, William Woodford, and Tiffany Ziebell, representatives to the departmental Committee on Graduate Students; Ahmed Al-Obeidi, publicity chair; Megan Brewster, alumni chair; Tracey Brommer, Johanna Engel, Kevin Gotrik, and Sophie Poizeau, alumni committee; and Heather Murdoch, Elizabeth Rapoport, and Melissa Smith, Graduate Student Council representatives.

These student organizations are invaluable resources, acting as departmental ambassadors to prospective undergraduates and graduate students. They also took on much of the responsibility for organizing a registration day barbecue, held outside Building 6 and attended by DMSE students, faculty, alumni, and staff. Our students continue to be active in outreach roles. DMSE graduate students completed their first

Science Outreach Month this spring. During this pilot program, the graduate students of DMSE performed materials science demonstrations for more than 220 children in third, fourth, and fifth grades. DMSE graduate students traveled to four schools in three cities to present on a variety of topics ranging from fuel cell cars to the science of ice cream. The DMSE Science Outreach Month was organized and sponsored by the Graduate Materials Council in an effort to create the materials scientist of the future. The presentations and demonstrations dealt with many complex concepts, including crystal structure and the conservation of energy.

## **Personnel**

On July 1, Dr. Jeffrey C. Grossman will join DMSE as an associate professor of materials science and engineering. He fills one of four tenure-track positions created by the School of Engineering, one each in the areas of computational engineering, energy, green technologies, and transportation. Dr. Grossman holds a BS in physics from Johns Hopkins University and an MS and PhD in physics, both from the University of Illinois at Urbana-Champaign. He formerly held the position of group leader of the Computational Nanoscience Group and executive director of the Center of Integrated Nanomechanical Systems, both at the University of California, Berkeley. His research background is in computational materials science as applied to specific problems in energy technologies such as photovoltaics, carbon nanotubes, and thermoelectric materials. Dr. Grossman is well known for his research in energy issues, using computational materials science and working with experimentalists. In the past, he has taught classes on the business of nanotechnology and on computational nanoscience.

Effective July 1, 2009, professors Darrell J. Irvine and Francesco Stellacci will be awarded tenure and professors Randolph Kirchain, Jr., and Krystyn J. Van Vliet will be promoted to associate professor without tenure.

Professor Michael Cima became faculty director of the Lemelson-MIT Program, effective January 1, 2009. This program recognizes outstanding inventors, encourages sustainable new solutions to real-world problems, and enables and inspires young people to pursue creative lives and careers through invention. They administer the InvenTeam initiative, awarding grants to teams of high school students, teachers, and mentors to invent, and the Lemelson-MIT Awards. The previous director was professor Merton C. Flemings.

On June 30, professor Robert Rose stepped down as Concourse director. He holds a SB in physical metallurgy and a ScD in metallurgy and materials science, both from MIT. He joined our faculty in 1961. Among his awards and honors are the Bradley Stoughton Award from the American Society for Metals and the Kappa Delta Award from the American Academy of Orthopaedic Surgeons. Professor Rose officially retired in 2003 but continued his involvement with Concourse, one of MIT's integrated studies programs.

## **Research Highlights**

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

Professor W. Craig Carter's group produces models of materials processes and properties. Recently, they addressed a diverse set of topics, including computations of van der Waal's forces between carbon nanotubes, thermodynamics and kinetics of phase transformations at grain boundaries, stability conditions of ionic colloidal crystals, phase stability and kinetics in electroactive nanoparticles, phase field modeling of ternary alloys, and models of anisotropic solid state dewetting. Professor Carter has also been developing educational software for teaching solid state chemistry concepts that can be seen at <http://pruffle.mit.edu/atomiccontrol/> and <http://pruffle.mit.edu/VirtualLab/>.

A collaboration with Neri Oxman of MIT's Media Lab has produced algorithms for art that is then fabricated using three-dimensional printing and numerically controlled machining. This collaboration produced three installations in New York's Museum of Modern Art (MOMA) and the pieces are now part of MOMA's permanent collection. The collaboration also produced three installations for the 2009 Biennale in Seville.

Most recently, his group has collaborated with professor Yet-Ming Chiang's group on modeling and characterizing lithium ion battery materials for hybrid and plug-in hybrid electric vehicles. They have produced models for the sequence of phase transitions in lithium iron phosphides as a function of particle size and overpotential. They have observed and characterized the model predictions in situ by using synchrotron radiation. The two groups are actively designing new battery architectures.

In collaboration with Professors Irvine (DMSE) and Cohen (Chemical Engineering), professor Michael Rubner has developed a new process for attaching nanoscale-thickness polymer backpacks onto living immune system cells. Before attachment, the polymer backpacks can be loaded with a wide range of functional materials, including cancer drugs, imaging molecules, and magnetic nanoparticles. After attachment, B cells and T cells remain viable and, since only a portion of their cell surface has been occluded by the backpack, are able to carry out their normal functions such as cell migration. This approach allows cell surface properties to be altered, arming cells with new functions while still allowing cell-environment interactions and avoiding interference with native cell functions. The strategy developed is applicable to many different cell types, though immune system cells have been the primary focus, including murine B lymphocytes and dendritic cells and human T cells. Although still in the early stages of development, this work opens up the exciting possibility of having immune system cells selectively target, carry, and deliver therapeutic drugs to disease sites.

In collaborative work with Professor Van Vliet, Professor Rubner has demonstrated that the amount of bacteria colonization of a surface can be controlled simply by controlling the hydrated modulus of the surface. This work demonstrated for the first time that swollen, low-modulus coatings can resist attachment of prokaryotic cells (bacteria). In addition, by utilizing a stimulus-responsive polymer coating rich in positive charges, an effective, easily applied antibacterial coating was developed with reversibly tunable properties. The ability to reversibly switch from one state of modulus and positive charge density to another with this coating makes it ideally suited for studying the factors governing bacteria attachment and killing. In addition, the stimulus-responsive nature of the coating may provide a pH-triggered cleaning mechanism that could prove useful against biofilm formation, a major health hazard.

In the past year, professor Carl V. Thompson's group has achieved several significant milestones in developing processing techniques for producing arrays of one-dimensional nanostructures and nanomaterials for use in microsystems such as next-generation electronic circuits. Through catalyst engineering studies, Professor Thompson's group has discovered ways to produce arrays of carbon nanotubes (CNTs) with controlled numbers of tubes per area and with controlled diameters and chirality (which strongly affects electronic conductivity). In addition, through collaborations with Intel Corp., Professor Thompson's group has developed processes for low-temperature growth of CNTs on metallic underlayers in ways that are compatible with processing of silicon-based integrated circuits.

In other work on one-dimensional nanostructure arrays, Professor Thompson's group developed techniques for producing aligned single-crystal silicon nanowires in arrays with separately controlled wire diameters, spacing, and length and with controlled ordering symmetry. This accomplishment was achieved at room temperature on silicon substrates using a combination of metal-catalyzed etching and interference or block-copolymer lithography. Current research is focused on using these structures in on-chip power management and energy storage devices. Applications in sensing and biotechnology are also under investigation.

Through collaborations in the Singapore-MIT Alliance, Professor Thompson's group developed a new technique in which microfabricated arrays of cantilevers and a special deposition technique enables combinatorial studies of the properties of binary and ternary alloy systems in single deposition and characterization processes. As an application of this technique, they studied metal alloy systems that readily form metallic glasses and demonstrated a strong correlation between the volume change on crystallization and the ease of glass formation. New compositions that readily form glasses were also discovered. This work was published in *Science*.

Professor Harry Tuller's group focuses on how localized fields and illumination can be utilized to control defects and transport at electrochemical interfaces. Important progress was made in fabricating thin-film solid state ionic materials for use in microfuel cells and related devices. The principle of heterogeneous doping of grain boundaries for control of space charge regions in nanocrystalline films, leading to enhanced conduction, was demonstrated for the first time. New model mixed ionic–electronic conducting cathodes, which exhibit exceptional performance, while allowing for greater insight into the rate-limiting steps controlling such performance, were also identified.

Preliminary studies of thin-film transistors with semiconducting metal oxide channels, both in the dark and under illumination, demonstrated the feasibility of utilizing such structures to achieve controlled desorption of studied gases. This technique holds promise for developing a new generation of high-sensitivity sensors operating at reduced temperatures.

### **Awards and Honors**

Elected to the National Academy of Engineering (NAE) this year were Yet-Ming Chiang and Edwin L. Thomas. Election to the NAE is among the highest professional

distinctions accorded to an engineer and honors outstanding contributions to “engineering research, practice, or education, including, where appropriate, significant contributions to the engineering literature,” and to the “pioneering of new and developing fields of technology, making major advancements in traditional fields of engineering, or developing/implementing innovative approaches to engineering education.” Their citations read as follows: Yet-Ming Chiang, “For contributions to understanding of new energy storage materials and their commercialization”; and Edwin L. Thomas, “For development of novel photonic materials and determination of the morphology of block copolymers.”

Professor Yet-Ming Chiang gave the freshman keynote address in fall 2008. President Hockfield said she invited Chiang to deliver the keynote address because he personifies several MIT ideals: a passion for pursuing the outer limits of knowledge, a commitment to tackling the most pressing challenges of the day, and an entrepreneurial spirit.

Professor Thomas Eagar received the Fred Plummer medal and presented the Plummer Memorial Lecture at the American Welding Society in October, recognizing outstanding contributions to national education and training in welding.

Professor Klavs Jensen was named a finalist in the Association for Laboratory Automation’s Innovation Award at LabAutomation2009 for his work on microfluidic synthesis of nanomaterials at high pressures and temperatures.

Professor Christine Ortiz has won a 2009 Martin Luther King Jr. Leadership Award for her important and lasting impact on students, staff, and faculty at MIT. Professor Ortiz is also one of six distinguished university faculty scientists and engineers forming the 2009 class of National Security Science and Engineering Faculty Fellows.

Professor Caroline Ross was elected a Materials Research Society (MRS) fellow in 2009.

Professor Don Sadoway was one of *Technology Review’s* top 10 awardees for his research on an all-liquid battery. The research is being conducted by graduate student David Bradwell and includes the involvement of professor Gerbrand Ceder.

Professor Yang Shao-Horn (Mechanical Engineering, joint appointment with DMSE) received the Charles W. Tobias Young Investigator Award of the Electrochemical Society; this award recognizes outstanding scientific and/or engineering work in fundamental or applied electrochemistry or solid state science and technology by a young scientist or engineer. She also received the Tajima Prize of the International Society of Electrochemistry for her outstanding achievements in the field of electrochemical energy conversion and storage, especially for developing novel nanostructured materials for fuel cells and batteries.

*Popular Science’s* annual “Brilliant 10” list, recognizing top young scientists to watch, included professor Francesco Stellacci, whom they called “The Materialist.” He was noted for developing “a material that can suck twenty times its weight in oil out of a sample of water. The material can be used to clean up massive crude-oil spills, and some

have called the work a blueprint for scientists designing nanomaterials to help protect the environment.”

Professor Ned Thomas is among the 210 new fellows and 19 new foreign honorary members elected to the American Academy of Arts and Sciences. Professor Thomas was recognized with an honorary doctorate from the University of Ioannina.

Professor Harry Tuller was the Joseph Meyerhoff visiting professor at the Weizmann Institute of Science in summer 2008. He is honorable guest professor of Shizuoka University, Japan in 2009. In May 2009, he received an honorary doctorate from the University of Oulu, Finland, during a gala celebration. The Tuller group obtained a Chesonis Foundation fellowship as part of the MIT Solar Revolution Project designed to explore new materials and systems that could dramatically accelerate the availability of solar energy. A second fellowship from the MIT Energy Initiative is supporting Di Chen on fuel cell-related research.

Professor Krystyn Van Vliet received the Harold E. Edgerton Faculty Achievement Award, the Junior Bose Award for Excellence in Teaching, and the Joseph Lane Excellence in Teaching Award.

Michael Tarkanian received one of the 2009 MIT Excellence Awards under the Serving the Client category. At the awards ceremony, chancellor Phillip Clay said “The Department of Materials Science and Engineering is fortunate to have a patient and natural teacher in the Rapid Fabrication Laboratory....[Mike] is generous and flexible with his time, providing long blocks of walk-in hours when he will answer questions or help to design a part....The DMSE students call him ‘awesome’.”

### **Undergraduate Awards**

Richard Lin won a Marshall Scholarship, allowing him to study for up to two years at a British university. He is a double major in materials science and engineering and biology, with double minors in history and applied international studies.

The National Society of Collegiate Scholars selected Mihai Duduta '10 as one of the recipients of the Induction Recognition Award 2008–2009 Scholarship.

Invited to join Phi Beta Kappa this year were Pantea Khodami, Richard Lin, Reid Van Lehn, and Rachel Zucker.

Claudio A. Andreoni won the 6.963 CUDA @ MIT NVIDIA/MIT/Harvard-Rowland Institute first prize for the best IAP project on parallel computing with graphics processing units.

Ryan Bonaparte and Jesus Guardado were among the 55 students in the Office of Minority Education’s “Leaders and Laureates” program.

Among the students selected to the MIT Arts Scholars Program for the 2009–10 academic year were Mihati Chintapalli and Leah Nation.

The Horace A. Lubin Award for Outstanding Service to the DMSE Community was presented to Dian Ariesta.

Awards for outstanding seniors, class of 2009, went to Johann Komander and Rachel Zucker. Recipients of the outstanding junior awards, class of 2010, were Bryn Waldwick and Brian Baum. The three outstanding sophomores, class of 2011, were Kathleen Alexander, Mahati Chintapalli, and Lina Garcia.

The Best Internship Report was awarded to Elizaveta Y. Plotnikov; the two recipients of the Outstanding Senior Thesis Award were Johann Komander and Joy Perkinson.

### **Graduate Awards**

Nonglak Meethong, Yu-Hua Kao, and Ming Tang, working with professors Yet-Ming Chiang and Craig Carter, won the Materials Day Best Poster Presentation Award for "Nanoscale Olivine Compounds as High-Power Li-ion Battery Positive Electrodes for Transportation Applications."

Among the poster winners at the fall 2008 MRS meeting in Boston were Anna Bershteyn and Richard Yau. The poster, "Bioresorbable Nanoparticles Enveloped by Lipid 'Shells,' 'Onions,' or 'Flowers' as Synthetic Pathogens for Vaccine Design," was coauthored by Jose Chaparro of Chemistry and professor Darrell J. Irvine.

Yeon Sik Jung received the 2008 Best Paper Award at the Techcon conference, Technology and Talent for the 21st Century, in Austin, TX. The paper was titled, "Self-Assembled Block Copolymer Nanolithography for Nanoscale Device Fabrication."

David Bradwell was selected by BP Alternative Energy, an offshoot of the British oil giant, to spend two weeks traveling to Antarctica in late March, along with 50 students from around the world, including five other MIT students.

Receiving National Science Foundation Fellowships were Richard Baumer of the Demkowicz group, Tracey Brommer of the Kirchain group, Samuel Crawford of the Gradečak group, Katherine Hartman of the Buonassisi group in Mechanical Engineering, and Jill Rowehl of the Bulovic group in Electrical Engineering and Computer Science.

Mark Mascaro of the Ross group received an IBM Graduate Fellowship for 2009.

Charles Sing of the Alexander-Katz group received a National Defense Science and Engineering Graduate Fellowship.

Shiyun Ruan of the Schuh group was awarded an MIT-Xerox fellowship in September 2008. The Xerox fellowship program supports students with an interest in green processes and technologies, imaging and smart documents, and nanotechnology and microelectromechanical systems.

George Whitfield of the Kimerling group was awarded a Lemelson Foundation Presidential Graduate Fellowship and a renewal of his Intel Foundation PhD Fellowship award.



Kevin McComber was elected vice president of MIT's Graduate Student Council for AY2010.

Graduate Student Community Service Awards were received by Megan Brewster and Tiffany Ziebell.

Jeremy Mason received the Graduate Student Teaching Award and the Outstanding PhD Thesis Research Award.

Marco Bernardi was the recipient of the First-Year Graduate Student Exceptional Performance Award.

Hyunjung Yi received the award for an Outstanding Paper by a First- or Second-Year Graduate Student.

The John Wulff Award for Excellence in Teaching was made to Yoda Patta.

### **New Faculty Chair Appointments**

Nicola Marzari will be named Toyota associate professor of materials science and engineering effective July 1.

### **Future Plans**

Equipping and opening the LAM on the Infinite Corridor will occur this coming academic year. Construction is expected to be completed in November, and the lab will be equipped and functional shortly thereafter. Currently, a small committee is evaluating a suite of equipment to benefit researchers throughout the department. Research performed in the facility will be integrated with one of the DMSE main foci: energy and materials. We continue to integrate this research theme into all aspects of the department: curriculum, student activities, and outreach. Research efforts from the Chiang, Ceder, Grossman, and Tuller groups are garnering attention from media worldwide, as is apparent from the traffic on our news feed. Also generating great attention are the DMSE offerings on OpenCourseWare.

We continue to fundraise for fellowships in order to meet our goal of funding all first-year graduate students. A new fundraising initiative will establish a fund for student activities and enrichment, to be named for professor Walter S. Owen, former department head and long-time friend of MIT.

**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/>.*