Department of Materials Science and Engineering

The Department of Materials Science and Engineering (DMSE) is in a period of growth and transition. After years of increased enrollments at the undergraduate level, this June saw the graduation of the largest class of SB Course 3 students—numbering 58—in the department's long history. This coming fall, we will welcome another large class of sophomores, as well as a cohort of doctoral-track students larger than any in the past seven years. All of this student activity correlates well with the research expenditures of the DMSE faculty, which have been growing steadily for years and are presently at an all-time high. The department has maintained its first-in-the-nation ranking from US News and World Report and was again rated first in the QS World University Rankings (metallurgy and materials).

The 2011–2012 academic year was one of transition for DMSE. Carl V. Thompson, Stavros Salapatas professor of materials science and engineering and director of the Materials Processing Center, served as interim department head until October, when professor Christopher A. Schuh began his tenure. The Department Head Search Advisory Committee consisted of professors Lorna J. Gibson (chair), Alfredo Alexander-Katz, Samuel M. Allen, Angela Belcher, Mary Boyce (head of the Department of Mechanical Engineering), Darrell J. Irvine, Caroline A. Ross, Michael F. Rubner, and Krystyn J. Van Vliet; as a committee, they met with department constituents and began a process of evaluation that will be the basis of a strategic plan. The DMSE faculty also addressed the issue of strategic planning throughout the academic year and, in January 2012, held a two-day retreat at the MIT Endicott House aimed at addressing the main directions of the department for the coming years.

The Laboratory for Engineering Materials (LEM) was completed in January and officially opened in April. LEM, located on the first floor of Building 4 with access from the Undergraduate Teaching Laboratory on the Infinite Corridor, now houses prototyping and fabrication equipment for the use of faculty, students, and staff. An area of the lab designated for corrosion research was used as instructional space for 3.042 Materials Project Laboratory and 3.154 Materials Performance in Extreme Environments.

Research Initiatives

DMSE is extremely active in research, with an average per-faculty expenditure rate in the order of $1M this year and many major initiatives that are ongoing. This section highlights research initiatives that are new, are in a start-up phase, or have undergone major transitions or renewals recently.

The Materials Project (originally titled the Materials Genome Project, and the inspiration for the White House Office of Science and Technology Policy scientific program) is an open database of materials properties first envisioned by professor Gerbrand Ceder. Now a joint project with Lawrence Berkeley National Laboratories, it uses computational modeling to determine materials structures and properties and will greatly speed up the design and development of new materials.

DMSE faculty are participating in the Samsung-MIT Center for Materials Design in Energy Applications, which brings together researchers in solar energy capture, energy storage, and computational materials design to work on problems of interest to Samsung and to the world. The initial goals of the program are in two major technology areas: energy storage and photovoltaics. Professor Ceder leads the energy storage program and provides computational materials design support to all projects. Professor Jeffrey Grossman leads the photovoltaics program, which includes professors Vladimir Bulovic (Department of Electrical Engineering and Computer Science [EECS]) and Moungi Bawendi (Department of Chemistry). An additional program on functional layer-by-layer approaches for lithium-air anode protective barriers and new high-temperature fuel cell composite proton exchange membranes will be directed by professor Paula Hammond of the Department of Chemical Engineering, and other programs will be added in the future. The energy storage program will focus on Na batteries as a successor to Li-ion batteries, and the research will begin with computational modeling to explore materials and chemical reactions. The photovoltaics program will use computational and experimental methods to realize new ways of creating quantum dot solar cell materials with greatly enhanced efficiency, durability, and manufacturability. By using data from the Materials Project, the team is able to accelerate the design and development of lithium-ion conductor materials.

This year, the Tiffany & Company/MIT Partnership in Manufacturing was formed to educate students in advanced manufacturing of precious metals. The initial partnership will consist of five or six research and development projects involving students at the undergraduate level (each project will last six to nine months) and the graduate master's level. The codirectors of the partnership will be Michael Kane of Tiffany & Company and professor Thomas Eagar of MIT. Projects will be selected by a steering committee consisting of two representatives of Tiffany & Company and two MIT faculty members. The partnership will last for five years, with the potential of a five-year renewal in 2017. Research areas for the collaboration include directional solidification of platinum castings to reduce porosity, net-shape and powder processing of platinum and gold alloys for jewelry production, electroforming sterling silver sheets and pellets, and coloration of gold surfaces via surface chemistry modification.

Two of the current Singapore-MIT Alliance for Research and Technology (SMART) projects are headed by DMSE faculty. Professor Eugene A. Fitzgerald heads the Low Energy Electronic Systems interdisciplinary research group (IRG), which aims to identify new integrated circuit technologies that reduce energy per function, lower power consumption, and improve performance in the electronics infrastructure. In the future, use of integrated circuits will increase in wireless communication, power electronics, LED lighting, printing, displays, and computing. The research teams, comprising 50 researchers in total once the project is at its peak, will have expertise in materials, devices, and circuits. The initial technology goals are in the areas of power electronic systems, efficient communications, and multifunctional displays and lighting systems. The biosystems and micromechanics initiative headed by professor Krystyn J. Van Vliet will develop new technologies to address a variety of diseases and then make those technologies available to the health care industry. The initiative has four thrusts: bioengineering of molecules, bioengineering of cells, in-vitro cellular systems engineering, and in-vivo cellular systems engineering.

Undergraduate Education

With an incoming sophomore class of 50 students, DMSE's undergraduate enrollment will be 143 students, with 62.2% women, 23.8% underrepresented minorities, and 2.8% international students. Seventeen students are designated Course 3-A (a flexible degree program often taken by students intending to continue their education in the field of medicine, business, or law), and three students are designated Course 3-C (archaeological materials science). In addition, a steady number of students are now completing a double major. This past academic year, five students graduated with a double major, and eight current students are declared double majors. To better advise undergraduates who elect to pursue double majors or minors, DMSE academic staff is developing online departmental degree audits for students and advisors. The internship program continues to attract many DMSE undergraduates; 34 DMSE rising seniors and juniors are working at 29 host institutions during summer 2012, including 14 at overseas institutions.

Due to the steady enrollment growth, DMSE has added another faculty undergraduate advisor per class. The greatest stresses on our curriculum are in the laboratories. DMSE is committed to a deep, hands-on laboratory experience that is the centerpiece around which our curriculum is built. Laboratory work begins in the very first semester of the sophomore year. With more than 70 sophomores participating in these labs in the fall, DMSE is presently addressing the scalability of our laboratory teaching model. The opening of LEM earlier this year provided approximately 4,000 square feet of additional teaching laboratory space dedicated to materials corrosion, design, synthesis, and prototyping. We are also increasing our teaching staff engagement and have begun duplicating key teaching laboratory equipment to enable more parallel laboratory sections and a greater degree of direct hands-on education.

Graduate Education

The department's graduate enrollment remains strong, numbering 192 in fall 2011. Approximately 25% of graduate students are women, and 5.2% are underrepresented minorities. Ten DMSE students participate in the Program in Polymer Science and Technology. For fall 2012, we anticipate an incoming class of 48, approximately 21% of whom are women and 2% of whom are underrepresented minorities.

This spring, 32 students participated in the new oral qualifying procedure—the Thesis Area Examination—which combines an examination on core material with questions on the student's proposed thesis research. Preliminary information suggests that the faculty and students see this as a positive change, and further feedback will be gathered after the next group of students complete the examination. The Department Committee on Graduate Students (DCGS) will also continue its discussions on the materials covered in the core subjects.

Student Organizations

DMSE's student organizations are great ambassadors for our department and for our field. Their leaders are committed to finding new ways to improve student life in the department by organizing research presentations, career workshops, and social events.

The 2012–2013 Society of Undergraduate Materials Scientists officers are president Ester Lomeli, vice president Garrett Lau, co–social chairs Amanda Evans and Judy Deng, career development chair Erica Lai, recruitment chair Marisa Jasso, publicity chair Jason Lee, secretary/historian Colleen Loynachan, and co–lounge chairs Stephanie Schafer and Will Dickson.

The Graduate Materials Council (GMC) officers for 2012–2013 are president Alexandra Toumar; vice president Eric Jones; treasurer Jordan Chesin; secretary Kevin Spencer; academic committee members Sameer Joglekar, Kunal Mukherjee, and Nancy Twu; athletics chair Ian Matts; social chairs Paul Rekemeyer, Michelle Sing, Wei Yu, and Dina Yuryev; alumni committee members Wubin Bai and Sema Ermez; coffee hour chair Matt Humbert; DCGS representatives Alan Lai, Nick Thompson, and Adam Jandl; Graduate Student Council representatives Roger Jia, Corentin Monmeyran, and William Richards; outreach committee members Ami Yaacobi and Wen Zheng; publicity chair Vivek Singh; and Materials Research Society student chapter president Mehmet Onbasli.

Personnel

Two new faculty are joining our department on July 1. Antoine Allanore, the Thomas B. King assistant professor in metallurgy, holds a chemical engineering diploma from France's Ecole Nationale Supérieure des Industries Chimiques and an MSc and PhD from the Institut National Polytechnique de Lorraine. He has just completed postdoctoral work with professor Donald Sadoway's group. He uses the traditional discipline of metallurgy in innovative research in the areas of sustainable materials production and electrochemical materials processing; his research continues DMSE's strength in materials manufacturing while addressing new areas of great societal impact.

Niels Holten-Andersen, the John Chipman assistant professor of materials science and engineering, holds a BSc in biology and an MSc in cell biology from the University of Copenhagen, a BScHon in Molecular Biology from the University of Canterbury, and a PhD in biomolecular science and engineering from the University of California, Santa Barbara. He was previously a postdoc at the University of Chicago; his work on cross-linking, self-healing soft matter, and bio-inspired materials will help to move our department in bold new directions.

Effective July 1, 2012, Darrell Irvine will be promoted to full professor. Professor Irvine joined the MIT faculty in 2002 with a joint appointment in DMSE and Biological Engineering after receiving a BS/BPhil (1995) from the University of Pittsburgh and a PhD from our department (2000). Also effective July 1, Dr. Silvija Gradečak will be promoted to associate professor. Professor Gradečak joined the DMSE faculty in October 2006. Her research focuses on nanophotonics and electronics and is based on the synthesis, characterization, and integration of low-dimensional systems. She holds a diploma (1999) from the University of Zagreb and a PhD from the Swiss Federal Institute of Technology (2003), both in physics.

Dr. Meri Treska and Dr. Geetha Berera were appointed as full-time lecturers, recognizing their many contributions to undergraduate education. They have both served DMSE for many years, teaching in a range of sophomore and junior undergraduate laboratory subjects. Dr. Berera first came to MIT in 1992 as a postdoctoral associate and joined DMSE as a lecturer in 2000. Dr. Treska joined MIT in 1992 as a visiting scientist, started teaching in DMSE in 1993, and was appointed as a lecturer in 2001. Their new appointments will give them the opportunity to develop new laboratory modules and take leadership roles in the administration of the undergraduate lab sequence.

Mike Tarkanian was promoted to lecturer to recognize his increasing involvement in undergraduate core teaching. He will be the instructor in charge of the capstone design project, 3.042 Materials Project Laboratory, in addition to involvement in other undergraduate laboratories and experimental facilities including the Laboratory for Engineering Materials, the foundry, and the machine shop. He also runs the Making and Designing Materials Engineering Contest (MADMEC). Mike joined DMSE as a technical instructor in 2006 and was presented with the Infinite Mile Award in 2012.

Effective July 1, 2011, Edwin L. Thomas, department head and Morris Cohen professor of materials science, went on leave to become dean of engineering at Rice University. On September 1, 2011, professor Yoel Fink assumed the role of director of the Research Laboratory of Electronics. Samuel M. Allen, POSCO professor of physical metallurgy, will continue as chair of the MIT faculty in AY2013.

Research Highlights

Many exciting research developments have come out of DMSE this year, with hundreds of published journal articles and invited presentations and many patent filings as well. In the interest of space, a few research developments that were noteworthy enough to receive the attention of the MIT News Office this year are described briefly below.

Professor Sadoway's group has developed and initiated the commercialization of "liquid metal batteries," electrochemical energy storage systems that use three layers of abundant and inexpensive materials, in a molten state, to form the positive and negative poles of a battery sandwiching a layer of electrolyte. The advantages of the all-liquid battery include, importantly, a self-assembling design where the liquids separate by density and robustness against mechanical degradation that normally limits the lifetime of solid components in a battery. They have launched a start-up company to make large-scale batteries that can store energy generated by solar or wind power and then release it at a needed time, opening the door to leveling of energy production. By using magnesium for the negative electrode (top layer), a salt mixture containing magnesium chloride for the electrolyte (middle layer), and antimony for the positive

Figure 1. A prototype of the liquid metal battery. The cutaway shows the three layers. Courtesy Sadoway lab.

electrode (bottom layer), the battery delivers current as magnesium atoms lose two electrons, becoming magnesium ions that migrate through the electrolyte to the other electrode. There, they reacquire two electrons and revert to ordinary magnesium atoms, which form an alloy with the antimony. To recharge, the battery is connected to a source of electricity that drives magnesium out of the alloy and across the electrolyte, where it then rejoins the negative electrode. The system operates at a temperature of 700 degrees Celsius (1,292 degrees Fahrenheit).

Also in the area of energy storage, Professor Grossman and his collaborators have discovered how to use azobenzene-functionalized carbon nanotubes to store the sun's heat in chemical form. The conversion of solar energy directly into chemical fuel offers a new pathway for energy storage and delivery and could potentially lead to much less expensive solar storage devices with enhanced storage capacity and thermal stability. When nanoscale templates are used to shape and constrain the material's physical structure, it gains new properties in efficiency and duration of energy storage. Ultimately, the same concept should be applicable to other battery materials, allowing them to also be used for solar energy storage.

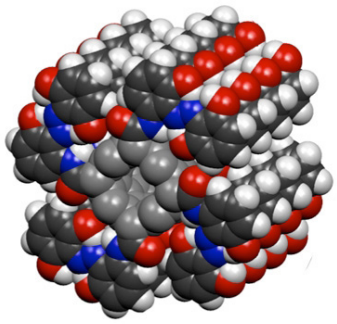

Figure 2. Azobenzene-functionalized carbon nanotubes have potential use as a novel solar thermal fuel. Courtesy Kolpak and Grossman.

In collaborative work in the domain of electronic materials processing, professors Lionel Kimerling and Caroline Ross have published research on a "diode for light": a gate that permits light to travel in one direction on a computer chip. This advance suggests that future optoelectronic systems can bypass a step in which light is converted to an electronic form, processed on the chip, and then reconverted to light. The materials design challenge was finding a material that is both transparent and magnetic, two characteristics that rarely occur together; a form of a material called garnet, which is normally difficult to grow on the silicon wafers used for microchips, inherently transmits light differently in one direction than in another and has a different index of refraction depending on the direction of the beam. By depositing a thin film of garnet to cover one half of a loop connected to a light-transmitting channel on the chip, light traveling through the chip in one direction passes freely, while a beam going the other way is diverted into the loop. This approach may boost data transmission speeds.

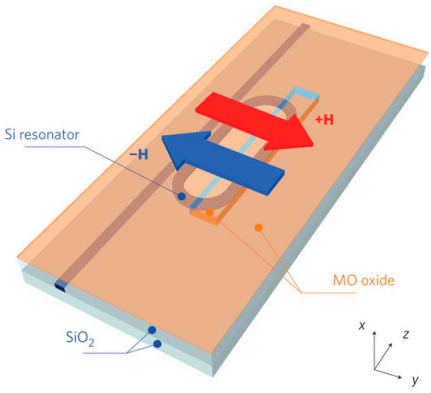

Figure 3. Schematic of the non-reciprocal optical resonator structure. Courtesy Ross and Kimerling.

Professor Krystyn Van Vliet, in her work using the concepts of materials science and materials mechanics, has made a significant discovery about how the mechanical interactions of molecules in the body affect biological processes. Many biological experiments are performed in dilute solutions, which means that the molecules being studied are arrayed loosely or in a "disorganized" manner and do not interact or communicate with one another significantly during the experiment. This is not necessarily relevant to the crowded environment of the body, where cells manufacture a matrix that controls the local structure. In their research, Professor Van Vliet and her collaborators introduced particles that they called "crowders" to a solution to better mimic the environment in the body; they showed that such crowding indeed leads to more complex organizations of cells. This research may be an important step in understanding how biological systems work as well as a step toward developing new methods of engineering proteins and tissue scaffolds.

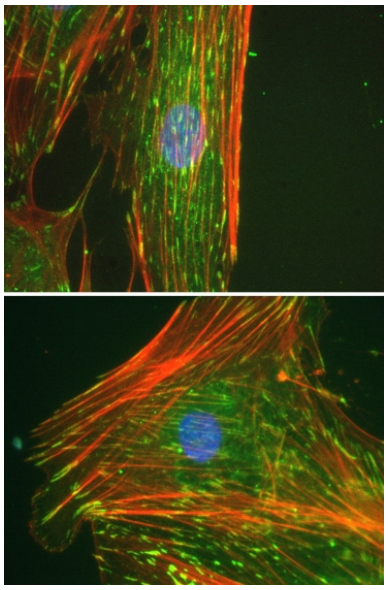

Figure 4. Proteins inside adult bone marrow-derived stem cells that were grown in the lab for three days, with (top image) and without (bottom) the 'crowder' particles. Cells grown with the crowders form neatly aligned structures. Courtesy Zeiger and Van Vliet.

Awards and Honors

Professor Antoine Allanore and James Yurko PhD '01 won the Minerals, Metals & Materials Society's Vittorio de Nora Award, which recognizes outstanding materials science research and development contributions to environmental improvements in metallurgical industries.

Professor Angela Belcher has been elected to the American Academy of Arts and Sciences. She is also one of the USA Foundation's "Nifty Fifty (times 2)," a group of scientists and engineers committed to visiting middle and high schools to encourage students to consider science, technology, engineering, and mathematics (STEM) careers.

Professor Craig Carter won the "Big Screw Award" for teaching 3.016 Mathematical Methods for Materials Scientists and Engineers. The competition awards a two-foot-long left-handed aluminum screw to the faculty member or staff person "most deserving of such an award"; the winner is determined by the amount of money contributed in his or her name, and all proceeds are donated to the winner's chosen charity. Professor Carter designated Camp Kesem, a camp for children whose parents have or have had cancer. According to the award website, this is the first time a Course 3 faculty member has won the competition.

Professor Yet-Ming Chiang received the Electrochemical Society's Battery Technology Award for 2012. This award encourages the development of battery and fuel cell technology.

Professor Michael Cima received the F.H. Norton Award from the New England section of the American Ceramic Society; the award, named for former DMSE professor Norton, recognizes "achievements and contributions to the advancement of ceramic science and technology."

Professor Eugene Fitzgerald was a corecipient of the 2011 Institute of Electrical and Electronics Engineers Andrew S. Grove Award. This award recognizes outstanding contributions to solid-state devices and technology; with professor Judy L. Hoyt of EECS, Professor Fitzgerald was honored for his "groundbreaking contributions involving strained silicon semiconductor materials [that] have enabled the continued shrinking of integrated circuits and faster chips and devices."

Professor Silvija Gradečak has been named the 2012 recipient of the Nano Letters Young Investigator Lectureship. This award, presented this year for the first time, recognizes the contributions of a young investigator who has had a major impact on the field of nanoscience and nanotechnology.

GMC has reestablished its awards recognizing faculty in this department. The 2012 GMC Teaching Award was presented to Professor Kimerling for 3.46 Photonic Materials and Devices, and the GMC Advising Award was presented to Professor Ross.

Professor Donald Sadoway was named one of *Time* magazine's 100 Most Influential People in the World in recognition of his pioneering work with liquid metal batteries.

Professor Subra Suresh has been elected to the National Academy of Sciences. In addition, the American Society of Mechanical Engineers (ASME) selected Professor Suresh as the recipient of the 2012 ASME Timoshenko Medal, the highest international recognition in the field of theoretical and applied mechanics. Professor Suresh is currently on leave while he is serving as director of the National Science Foundation.

Professor Harry Tuller and professor Bilge Yildiz of MIT's Department of Nuclear Science and Engineering will receive the Somiya Award from the International Union of Materials Research Societies. They are recognized for their work on the "Design of Ionic and Mixed Conducting Ceramics for Fuel Cell Application" project. The award will be presented in September in Yokohama, Japan.

Cambridge University Press published professor emeritus Robert W. Balluffi's new book, *Introduction to Elasticity Theory for Crystal Defects*, earlier this year. The book is drawn from his long tenure teaching "Defects in Crystals," a graduate-level subject.

Undergraduate Awards

Joshua P. Steimel was the recipient of the Outstanding Senior Thesis Award for "Synthetic Creation of a Chemotactic System via Utilization of Magnetically Actuated Microrobotic Walkers," advised by professor Alfredo Alexander-Katz. His work will result in several high impact journal publications and there is already a provisional patent in preparation for the use of his technology in high-throughput sensing applications. Josh will be continuing in our doctoral program this upcoming fall.

Ellen McIsaac received the Joseph M. Dhosi Internship Award. After graduation, she will start a job at Pratt & Whitney as a structures engineer for the Composite Structures Part Family (the same group with which she interned last summer). While at MIT, Ellen was active in the Society of Women Engineers chapter and FIRST Robotics Competition, and she worked in the Gradečak group. She also received the Edward L. Horton Fellowship Award and the Paul E. Gray UROP (Undergraduate Research Opportunities Program) Researcher Award.

The outstanding seniors, Class of 2012, were Michael A. Gibson and David Y. Young. Michael has completed his SB in three years while doing research at ISN and 24M, playing lacrosse, and performing outreach with Camp Kesem. He will begin our doctoral program in the fall. While working in professor Yet-Ming Chiang's research group for the past two years, David has answered an outstanding question regarding transport in the lithium battery anode $Li_4Ti_5O_{12}$, a material that is seeing rapid commercialization in industry.

Ester Lomeli received the Julian Szekely Award for Outstanding Junior; this award was recently named for late professor Julian Szekely in recognition of his excellence in teaching undergraduates, particularly the junior core, and mentoring students. Ester is also the 2012 recipient of the Horace A. Lubin Award for Service to the DMSE community. Ester is a cheerful and constant presence at events and has been a great asset in promoting the department and its programs to MIT. She is working this summer at the Institute for Particle Technology at the Technical University in Brunswick, Germany.

The outstanding sophomores, Class of 2014, are Erica L. Lai and Colleen Loynachan.

Michael Gerhardt, Hannah Israel, Ambar Mehta, Joshua Steimel, and Anjali Thakkar were all invited to join Phi Beta Kappa.

Graduate Awards

John Rogosic received the John Wulff Award for Excellence in Teaching. John has been a teaching assistant (TA) almost every term of his graduate studies and several times as an undergraduate; most of his assignments have been in 3.091 Introduction to Solid State Chemistry, but he has also taught in our senior capstone subject 3.042 Materials Project Laboratory and most recently was the TA for 3.022 Microstructural Evolution of Materials.

The Graduate Student Teaching Award was presented to Charles E. Sing, who was a TA in 3.20 Materials at Equilibrium under the supervision of professor Gerd Ceder. His teaching evaluation scores were the highest ever for a TA in this department.

The Best PhD Thesis Award was presented to Matthew J. Smith for "Femtosecond-Laser Irradiation as a Platform for Tailoring the Optoelectronic Properties of Silicon," advised by Professor Gradečak. Matt will continue as a postdoc in Professor Gradečak's group. Seong-Hoon Woo of professor Geoff Beach's group received the First-Year Graduate Student Exceptional Performance Award.

The Best Paper Award for a First- or Second-Year Student was presented to David Henri Michaël Cohen-Tanugi. David just received an SM in materials science and engineering and is beginning his doctoral research in Professor Grossman's group.

Sophie Poizeau, Elizabeth Rapoport, and Heather Murdoch tied for first-place in the Environment, Health, and Safety Office's Machine Shop Safety Video Contest. In their video, they take on the personas of flight attendants as they demonstrate proper safety procedures (e.g., pathways must be kept clear, and long hair must be secured at all times).

Staff Awards

Mike Tarkanian won a School of Engineering Infinite Mile Award for Excellence. Mike's service to the department is widely appreciated by students, staff, and faculty, and this honor is very well deserved. He works with DMSE students in 3.042 Materials Project Laboratory, 3.094 Materials in Human Experience, and the freshman blacksmithing seminar; he can usually be found in the foundry, the forge, or LEM, where his creativity and expertise in using DMSE's fabrication equipment are an invaluable resource for the whole department.

Future Plans

DMSE has just completed another exciting and successful year, marked by a transition in leadership and the development of a new strategic plan. The resulting strategic planning document will be finalized in the coming months and presented to the Visiting Committee in the fall. The overarching theme of concern in DMSE's strategic planning process this year was how to maintain excellence in research and teaching during a period of growth. As our enrollments climb, we are working to scale our laboratory-centric curriculum to accommodate more students. Ultimately, the scaling challenge for the educational mission of DMSE demands that we seek opportunities to increase not only the number of students we matriculate but the quality of their educational experience as well. We believe there is great promise in new pedagogical technologies that can transform our educational model and deliver an ever-better experience to our students.

This coming academic year, DMSE will pilot a new program for some of our junior-year students, offering them the ability to participate in DMSE classes remotely via an Internet connection. Developed under the leadership of Professor Fitzgerald, this "semester from anywhere" will include all of the elements of the MIT campus experience, including lectures, discussion and recitations, homework, and examinations. It will, however, also permit students to participate in other, immersive activities that complement their classroom experience, including extended internships and service learning projects that would not be possible without introducing such flexibility in our educational model. DMSE is also proud to begin extending our educational product to eager students outside of MIT, through the launch of our freshman-level class, 3.091 Introduction to Solid State Chemistry, on edX/MITx as of this coming fall. With more faculty training more students, with modernized facilities reinforcing a vibrant curriculum, and with pedagogical experiments incorporating modern communication tools into the traditional MIT campus educational model, we aspire to be the best possible home for any student looking to think deeply about materials to address big problems.

Christopher A. Schuh
Department Head
Danae and Vasilis Salapatas Professor of Materials Science and Engineering