Materials Processing Center

The Materials Processing Center (MPC) was established as an interdisciplinary center within the School of Engineering in response to a recognized national need to improve the materials processing knowledge base and to streamline the process of translating materials research results into industrial innovations and applications. MPC is now in its 35th year.

Following a science-to-systems approach, MPC works with faculty to assemble resources and leverage existing knowledge to help companies and federal agencies address fundamental challenges through research and create opportunities through technology transfer. MPC supports about 60 faculty and senior research staff with proposals for research and post-award program management. In addition, we provide administration services and liaison support with industry contacts outside of MIT. The center also organizes events for the broader materials research community at MIT, which includes more than 150 faculty.

Research volume for MPC over the past year was about $14.1 million, a decrease of 9% from the previous year. This continues a drop from a high of approximately $20 million in FY2012 but is still significantly above the low of about $8 million in FY2009. A significant portion of this decrease can be attributed to the ending of stimulus funding and the departure of senior faculty from MIT. MPC continued to support its main subcenters—the Microphotonics Center (MPhC) and the Skoltech Center for Electrochemical Energy Storage (CEES)—as well as Professor Harry Tuller's large multifaculty program (Chemomechanics of Far-From-Equilibrium Interfaces) and the Low Energy Electronics Systems interdisciplinary research group (IRG) of the Singapore-MIT Alliance for Research and Technology (SMART). New initiatives include Professor Raymond Ashoori's Center for Integrated Quantum Materials.

Industry Collegium and External Advisory Board

The MPC Industry Collegium consists of 10 companies that provide direct financial support for the center's discretionary activities through annual donations. Representatives from these companies work with MPC throughout the year to identify opportunities for collaboration and participate in MPC's annual Materials Day symposium and poster session. Current collegium members include the Agoria-Belgium Consortium, Applied Materials, Ishikawajima-Harimi Heavy Industries, Merck KGaA, Michelin, POSCO, Raytheon, Siam Cement Group, Stanley Black & Decker, and SunEdison Semiconductor. Growth of the collegium membership is a high priority for MPC.

The MPC external advisory board meets for a full day after the Materials Day event each year. MPC's director and staff report on the prior year's activities and present on planned initiatives and goals for subsequent years. In addition, new faculty present their planned research for the year and senior faculty discuss major new initiatives. The external advisory board provides valuable advice on program development and management. It also assists in identifying opportunities for interactions with industry. The board meeting culminates in an oral and written report to the dean of

the School of Engineering or a designated representative. Current board members represent 3M, Applied Materials, Boston University, Charles Stark Draper Laboratory, Compaq Computer Corporation, General Motors, Lockheed Martin Corporation, Lord Corporation, Midrange Systems EMC, Novartis Pharmaceuticals, Saint-Gobain Corporation, Sandia National Laboratories, Solvay Advanced Polymers, and SunEdison Semiconductor.

New faculty members who spoke at this year's board meeting included Assistant Professor Juejun Hu (Materials Science and Engineering), Assistant Professor Elsa A. Olivetti (Materials Science and Engineering), Assistant Professor Xuanhe Zhao (Mechanical Engineering), and Assistant Professor Heather J. Kulik (Chemical Engineering).

Center for Electrochemical Energy Storage

The Center for Electrochemical Energy Storage continued into its second year in 2015. The expected steady-state annual funding level at MIT for this five-year program was $2.5 million. However, CEES receives its funding in Russian rubles, and, due to a decrease in the value of the ruble, 2015 funding dropped to approximately $1.3 million. Funding is anticipated to remain at this level for the coming year.

Research in CEES is focused in three thrusts—advanced metal-ion batteries, rechargeable metal-air batteries, and fuel and electrolysis cells—chosen to target the technologies that will replace the current Li-ion battery technology. The center is also conducting a project addressing general methods for systems-level analyses. Research on advanced metal ion batteries focuses on earth-abundant ions such as Na^{+} as replacements for more expensive Li^{+} ions and on polyvalent ions such as Al^{+3} that will provide batteries with higher energy capacities. These alternative ions will require new electrode and electrolyte materials; design, synthesis, and testing of these materials is the focus of initial work in the center. Li-sulfur and metal-air batteries offer the potential for significantly improved capacities over even advanced metal-ion batteries but require new materials and design principles. Research in this area is therefore focused on discovery of fundamental principles that govern reversible electrochemical growth of metal sulfides and oxides and application of these principles in materials and device design. Coupled solid oxide fuel and electrolysis cells offer the possibility of chemically storing energy at high density as fuel. Fuel and electrolysis cells share a need for improved electrode and catalytic materials for improved performance. In this case, the morphology of the electrode plays a particularly important role and is therefore included in the process of materials and system design.

The CEES team is highly interdisciplinary and involves faculty from the MIT Departments of Mechanical Engineering, Chemical Engineering, Materials Science and Engineering (DMSE), and Chemistry as well as faculty from the Departments of Physics and Chemistry at Moscow State University (MSU). The Skoltech center director is now in residence in Moscow, and several newly recruited Skoltech faculty are now associated with the center.

A number of important milestones were achieved this year. To date, there have been 12 publications and numerous conference presentations based on work performed in the center. MIT faculty were also instrumental in organizing and participating in the first annual "Electrochemical Energy Storage: Challenges and Prospects" workshop held at MSU. In addition, two Skoltech students whose research was carried out through the center have received master's degrees and will continue to work toward their PhD degrees. Other students are now active in research associated with the center and will be in residence at MIT next fall.

Microphotonics Center

The Microphotonics Center was established in 1999 based on research on silicon photonic device integration and applications to support the demand for exponential growth in communication bandwidth that has enabled the information age.

MPhC performs research and technology supply chain studies that are released periodically in the form of the MIT Communications Technology Roadmap (CTR). The CTR is coordinated by the center's industry consortium, and reports are written by faculty and by industry-led technology working groups. The purpose of the CTR is to define difficult challenges and identify potential solutions. CTR releases thus far are as follows:

- CTR I (2000–2005) focused on industry trends and areas for technology development such as electronic-photonic synergy, integration, standardization, and cross-market platforms.
- CTR II (2005–2009) identified market opportunities for electronic-photonic convergence and technology targets (cost, power efficiency, bandwidth density).
- CTR III (annual releases) focused on scaling energy (2010), scaling copper (2011), short-reach and board-level optical interconnections (2013), and open architecture system optimization (2014).

MPhC's activities are supported by 28 companies, 12 academic affiliates, 7 roadmap organizations and national labs, and more than 100 participating roadmap study organizations. Its membership meets twice each year to review silicon microphotonics research in the fall and the CTR in the spring. The fall and spring meetings include members, invited speakers, and guests. Interest in the center's activities has grown significantly over the past four years, as represented by the number of individuals and organizations in attendance. More than 100 organizations—representing industry, government, and university groups—participated in the fall 2014 and spring 2015 meetings. Contributing members over the past year have included 3M, Acacia Communications, Alcatel-Lucent, Boston University, Cisco, Dow Corning, Facebook, Hewlett Packard, Intel Corporation, the MIT Materials Systems Laboratory, Palomar Technologies, SABIC Innovative Plastics, the University of Delaware, the University of Southampton, and Waseda University.

The Microphotonics Center and the International Electronics Manufacturing Initiative (iNEMI) were awarded a grant from the National Institute of Standards and Technology to address the technology gaps and challenges that are limiting the advance of hardware

technology for integrated photonic system manufacturing. The effort will establish a consortium of academics, technologists, and companies that will create an integrated photonic technology roadmap; bring together the fragmented, customization-focused photonics industry to engage collaboratively in developing a common roadmap; support the development of high-volume mass-manufacturing, assembly, and packaging technologies and processes that are reliable and cost-effective; integrate the CTR III to develop dynamic models of supply-chain function and interaction as the transition to integrated photonics occurs; and develop technology-based models for the cost and environmental implications of a transition to integrated photonics.

Along with the Research Laboratory of Electronics, MPC participated in the development of a major proposal for creation and funding of the American Institute for Manufacturing Integrated Photonics (AIM Photonics) as part of the Nationwide Network for Manufacturing Innovation initiative. It has been announced that this proposal was successful. The lead institution in this $600 million private-public partnership is the University of New York Polytechnic Institute. Through MPhC, MPC will play important roles in education and workforce development as well as in research.

Singapore-MIT Alliance for Research and Technology Low Energy Electronic Systems

The SMART Low Energy Electronic Systems IRG, directed by Professor Eugene A. Fitzgerald and managed through MPC, is now in its fourth year. This program has an MIT/MPC research volume of $1.7 million per year, with a corresponding Singapore volume of about three times that amount. The program aims to identify new integrated circuit technologies that become the new added value for reduced energy per function, lower power consumption, and higher performance systems, based on the use of current silicon integrated circuit wafer processing infrastructure and integration of compound semiconductor device technology. A major research facility has been constructed in Singapore for this program. The facility includes two state-of-the art metal organic chemical vapor deposition systems as well as other components such as a wafer bonding and chemical mechanical polishing system. Coupled with other facilities available through collaborations with the Nanyang Technical University (NTU) and the National University of Singapore (NUS), full capabilities for III-V device processing on silicon substrates are now available. A collaboration with Global Foundries in Singapore has also been established for silicon complementary metal-oxide-semiconductor (CMOS) wafer processing, establishing the ability to create novel monolithic III-V and silicon CMOS using foundry design platforms.

The SMART program involves seven MIT faculty and one MIT senior research scientist, as well as their students and postdocs based at MIT. Thirteen faculty from NTU and NUS are also involved in collaborative research. Seventeen MIT staff and postdocs are now supported in Singapore for research based there. A number of NTU and NUS students are also involved in the program.

Selected New Programs with Industry

MPC continues to support faculty research efforts with industry collaboration over a wide range of materials science–based applications, from metallurgical coatings for strength and corrosion resistance to integrated photonics, solar cells, and batteries. MPC supports many ongoing research programs with faculty, including Professor Christopher Schuh's research with Mitsubishi Materials and POSCO, Professor Lionel Kimerling's programs with iNEMI, Professor Antoine Allanore's program with Terrativa, Professor Donald Sadoway's research with NorCo, Dr. Randy Kirchain's research with Hydro Aluminum and the Hangzhou Jinjiang Group, and senior research scientist Jurgen Michel's work with the Advanced Research Projects Agency-Energy.

MPC also supports faculty with the establishment and operation of consortium research programs with industry. Two ongoing programs for 2014 and 2015 include the Materials Systems Laboratory (Professor Joel Clark and Dr. Randolph Kirchain) and the Microphotonics Center (Professor Lionel Kimerling, director).

MPC partners with MIT Industrial Liaison Program (ILP) officers in support of company inquiries and ILP members' interests associated with faculty research supported through the center. MPC support includes coordination with faculty for meetings as well as technical briefings and seminars offered by the MPC director and associate director. Significant company meetings coordinated with ILP officers throughout the year were held for senior executives and researchers from Applied Materials-Varian, Sabic Innovative Plastics, Siam Cement Group, and Xuzhou Construction Machinery Group. All are either members of ILP or participate in the MPC Industry Collegium or Microphotonics Center Consortium. MPC also supports other major events sponsored by ILP, including its research and development conferences in Japan and at MIT.

MPC collaboration with ILP included a two-week visit by ILP members to the city of Wuxi and the greater Jiangsu region of China. The visits were coordinated and hosted with the Wuxi Xishau District Science and Technology Bureau and the Jiangsu Science and Technology Department's International Cooperation Division. MPC's associate director presented five seminars in Wuxi and Beijing that covered a wide range of MIT faculty members' materials research activity. Topics included materials and processing for energy storage and harvesting, metallurgy, polymers, coatings, composites, communications systems, and sensors. The visit included meetings with 17 companies and three university research institutes and presentations tailored to companies' specific business and research interests. Significant interest in MIT materials research was generated, leading to multiple follow-on inquiries regarding sponsored research collaborations.

Promotions and Selected Honors and Awards

MPC faculty received numerous awards and honors, as individually reported in the reports of their home academic departments. Some highlights are listed below.

Ibrahim I. Cisse, Assistant Professor of physics in the School of Science, was one of the recipients of the NIH (National Institutes of Health) Director's New Innovator Award, which addresses two important goals: stimulating highly innovative research that has the potential for significant impact and supporting promising early-stage investigators.

The award, totaling $2.34 million over 5 years, will be used to conduct research on imaging transcription with single-molecule resolution in live mammalian cells. Transcription is the first step in the central dogma of molecular biology, when genetic information encoded on DNA is made into RNA. How this process occurs in eukaryotes is well characterized in vitro but surprisingly poorly understood at the cellular level. This is in part because conventional live cell imaging approaches fail to capture with sufficient quantitative detail the intricate, weak, and transient molecular interactions that regulate eukaryotic transcription process in vivo. To surmount these limitations, novel quantitative imaging methods will be used that enable probing eukaryotic transcription with high spatial and temporal resolution. Investigations will focus on how the spatiotemporal organization and dynamics of RNA polymerase II, the molecular enzyme responsible for the transcription of all protein encoding genes, regulate gene expression in individual living cells.

Nuh Gedik, the Lawrence C. (1944) and Sarah W. Biedenharn Career Development Associate Professor of Physics, was granted tenure in the School of Science. Gedik uses advanced optical techniques for investigating and manipulating the properties of quantum materials such as topological insulators and high-temperature superconductors. Using ultrafast laser pulses, he studies processes in solids that take place within femtoseconds and at lengths of angstroms. Gedik employs these techniques to search for solutions to important problems in condensed matter physics, with a primary focus on understanding the mechanisms behind the unique properties of strongly correlated electron systems.

Pablo Jarillo-Herrero, the Mitsui Career Development Associate Professor of Physics, was also granted tenure in the School of Science. Jarillo-Herrero explores quantum transport in novel condensed-matter systems such as graphene, transition metal dichalcogenides, and topological insulators. He won an award totaling $411,891 for his recent work on quantum transport in twisted van der Waals heterostructures. In addition, he is researching novel quantum spin Hall and photothermoelectric effects in graphene, as well as light-emitting diodes, photodetectors, and solar cells in the atomically thin tungsten diselenide system. He has also made advances in characterizing and manipulating the properties of other ultrathin materials, such as ultrathin graphite and molybdenum disulphide, that lack graphene's ultrarelativistic properties but possess other unusual electronic properties.

Liang Fu, assistant professor of physics, received the 2014 Packard Fellowship in science and engineering. Fu develops predictive theory to search for new quantum phases of matter in real materials and explores their novel properties. He seeks to understand collective behaviors of solids using concepts and techniques from theoretical physics, quantum chemistry, and quantum information science. His work on topological quantum materials has potential applications in quantum computing and nanoelectronics.

Of particular note, we wish to acknowledge George Benedict, Caspar Professor of Physics. A longtime MPC participant, he has wound down his research efforts after a highly successful career dedicated to work on phase transitions, self-assembly,

and aggregation of biological molecules. Among numerous achievements, five of his graduate students have become MIT professors, and several others have become faculty members at other institutions.

Communications and Outreach

The increasing shift to online information transfer has catalyzed a more focused initiative utilizing the website as a campus-wide materials reporting resource. The MPC website has become a highly successful portal for materials news and events within the MIT community. The website is updated regularly and highlights the latest news stories generated for our e-newsletter, as well as related news from the MIT News Office. Each month a faculty member is highlighted along with the research activities of his or her graduate students and postdocs. Faculty profiles in 2014–2015 included Polina Anikeeva, Michael Rubner, Bilge Yildiz, Christopher Schuh, William Tisdale, Vladimir Bulović, Krystyn Van Vliet, Juejun Hu, Pablo Jarillo-Herrero, W. Craig Carter, and Elsa Olivetti. This year 51 original articles were written and photographed for the e-newsletter, and 39 of those articles were picked up by the MIT News Office for use on its own website. DMSE, the School of Science, and the School of Engineering also picked up several articles for use on their websites.

We continue to use social media (Twitter, Facebook, and Google+) to communicate with and expand our audience. As a result, we have grown our following by almost double from last year, and now other MIT organizations are sharing our Twitter posts with their followers. Over the past year, we had more than 15,000 impressions on our tweets.

Summer Research Internship Program

MPC does not limit its educational outreach to the MIT community. For 32 years, it has co-sponsored with the Center for Materials Science and Engineering (CMSE) a summer internship program for promising undergraduate researchers from other colleges and universities nationwide. The MPC-CMSE summer internship is a National Science Foundation (NSF) Research Experiences for Undergraduates program. The program brings the best science and engineering students in the country to MIT for graduate-level materials research in the laboratories of participating faculty. The program culminates in a poster session held in the lobby of Building 13, where students present their research to the MIT community.

The 2015 nine-week program ran from June 7 to August 8 and involved 12 faculty and 12 students from schools including Lehigh University, Pennsylvania State University, Universidad del Turabo (Puerto Rico), Rowan University, the University of Florida, the University of Massachusetts Amherst, Rutgers University, the University of Pennsylvania, Hope College, the University of Maryland at College Park, and Columbia University.

2014 Summer Scholars.

Materials Day

Sharing knowledge and insight with others in the materials science and engineering field can lead to new ideas, collaborations, and breakthroughs. Once a year, the materials community is invited to Materials Day, a celebration to recognize and honor the many important accomplishments and achievements of the past year and to talk about the future.

Held in the fall, Materials Day is a daylong symposium on a featured topic related to materials science and processing, followed by a graduate student/postdoctoral associate poster session. The Materials Day 2014 symposium focused on new frontiers in metals processing and looked back at the 35-year legacy of MPC and how its widening focus has come to define an interdisciplinary hub of activity today. Seven presentations were offered over the course of the day, by both faculty and industry professionals, drawing a crowd of more than 118 attendees.

Invited speakers (and the titles of their talks) included Dr. Louis G. Hector, Jr., General Motors technical fellow ("Integrated Computational Materials Engineering (ICME) of Generation Three Advanced High Strength Steels"); Professor Christopher Schuh, MIT ("Nanocrystalline Metals Stabilized for Commercial Use"); Dr. Slade H. Gardner, Lockheed Martin Space Systems Company ("Advanced Materials and Manufacturing at Lockheed Martin"); Professor Donald R. Sadoway, MIT ("Towards Sustainable Metal Production by Molten Oxide Electrolysis"); Dr. J. David Rowatt and Dr. Manuel Marya, Schlumberger-Doll Research ("Metallurgy in the Oil & Gas Industry—A Wellbore Perspective"); Associate Professor Bilge Yildiz, MIT ("Uncovering the Inner Workings of Metal Corrosion by Combining Surface Sensitive Experiments and Multi-scale Modeling"); and Dr. Adam C. Powell, INFINIUM Inc. ("Clean Metal Production for Clean Energy"). MPC Director Carl V. Thompson led the opening welcome presentation.

The poster session that followed panel presentations and discussions included over 70 posters presented by graduate students and postdoctoral associates from departments including Chemical Engineering, Chemistry, Civil and Environmental Engineering, Electrical Engineering and Computer Science, Aeronautics and Astronautics,

Materials Science and Engineering, Mechanical Engineering, Nuclear Science and Engineering, Biological Engineering, and Physics. The posters were judged by a panel of representatives from industry as well as members of the MPC advisory board. Winners received award certificates and $500 prizes. Poster session winners were as follows:

Zachary C. Cordero, DMSE

"Powder Processing of Ultrafine Grain, Tungsten-bearing Alloys"

Faculty advisor: Professor Christopher Schuh

Michael Gibson, DMSE

"Trends in Segregation Energies and Their Connection to Embrittlement"

Faculty advisor: Professor Christopher Schuh

Joseph Azzarelli, Chemistry

"Wireless Detection of Gases and Vapors with a Smartphone via Near Field Communication"

Faculty advisor: Professor Timothy M. Swager

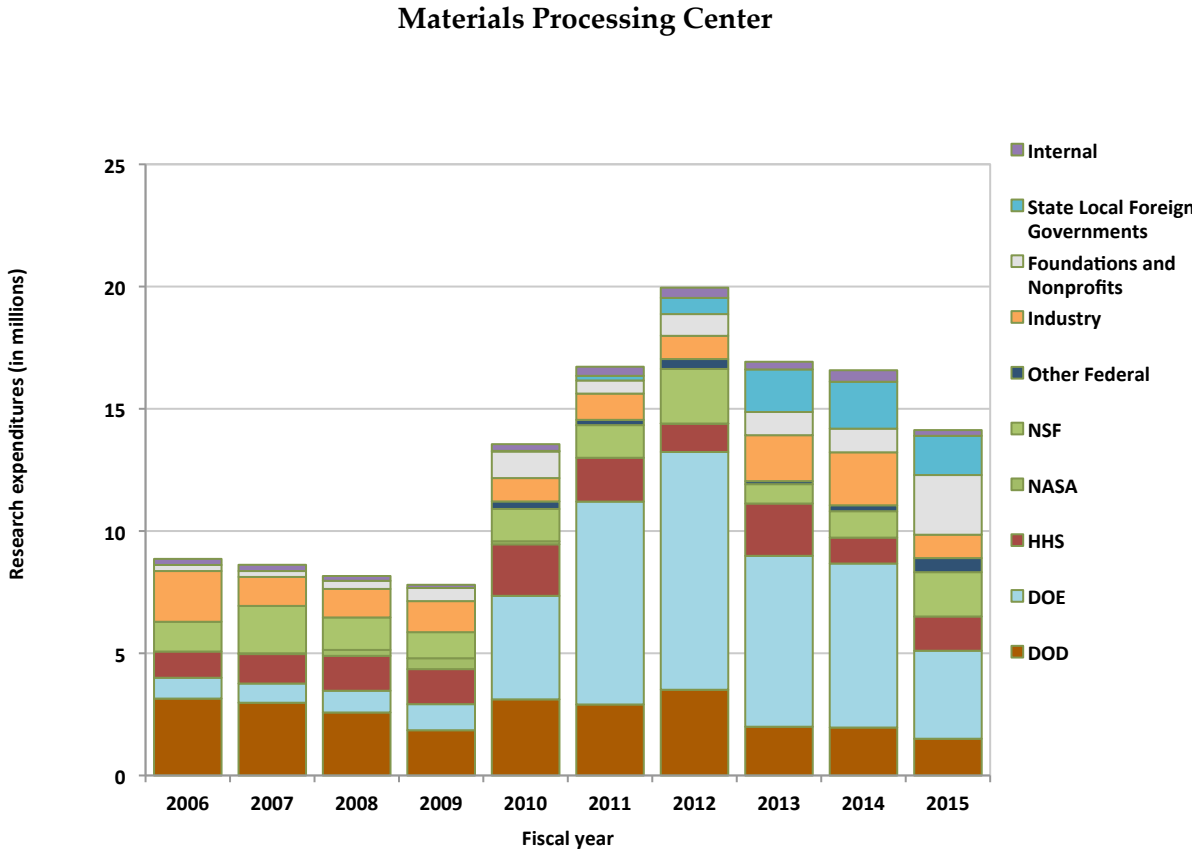
Materials Day 2015 is scheduled for October 14, 2015, and the workshop will focus on quantum materials.

Materials Day 2015 Poster Session winners, from left to right Mark Beals, associate director, MPC; Alice White, MPC advisory board member; Joseph Azzarelli (Chemistry); Zachary Cordero (Materials Science & Engineering); Michael Gibson (Materials Science & Engineering); Carl V. Thompson, director, MPC.

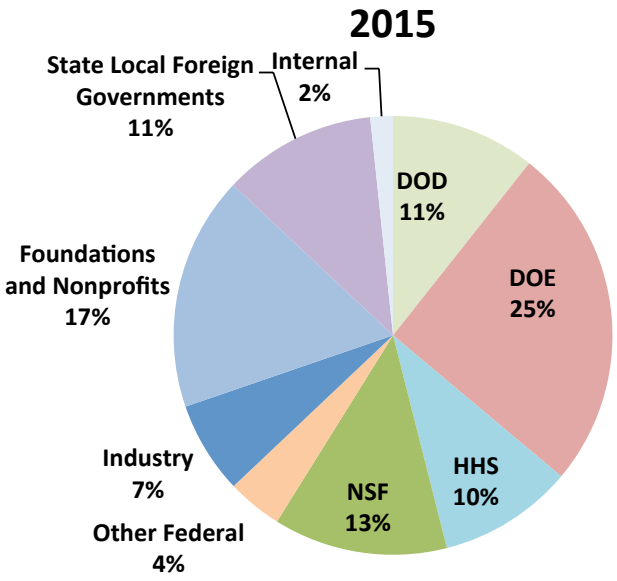
Research Volume

Total expenditures under MPC totaled $15.6 million in FY2015. Major program expenditures included the Low Energy Electronic Systems program within SMART, led by Professor Eugene Fitzgerald and eight co–principal investigators (PIs); the Skoltech Center for Electrochemical Energy Storage, led by Professor Carl V. Thompson and seven co-PIs; the Chemomechanics of Far-From-Equilibrium Interfaces program, supported by the Department of Energy (DOE) and led by Professor Harry Tuller and five co-PIs; and the NSF-supported Center for Integrated Quantum Materials, in collaboration with Harvard University and led by Professor Raymond Ashoori and seven co-PIs. Other significant faculty research groups included those of Associate Professor Pablo Jarillo-Herrero, Assistant Professor Jeffrey Gore, Associate Professor Nuh Gedik, Dr. Jurgen Michel, Assistant Professor Antoinne Allonare, and Assistant Professor Ibrahim Cisse.

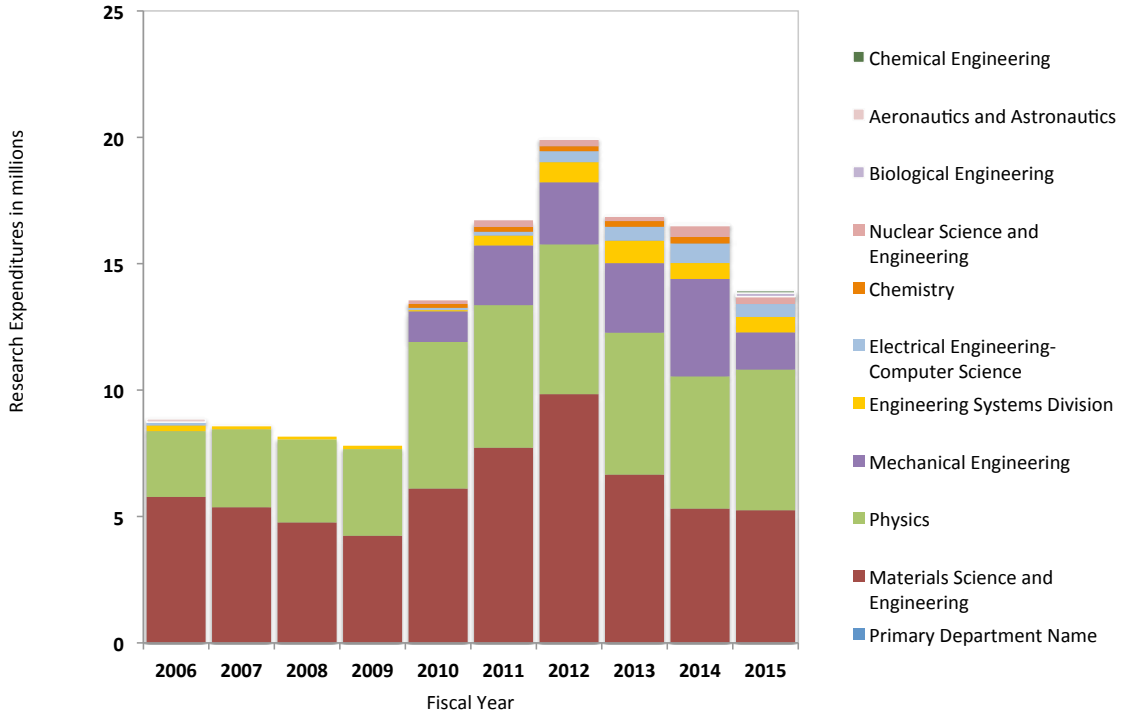
MPC researchers are sponsored not only by a variety of companies but also by nearly every major federal research sponsoring agency, including NSF, DOE, NIH, and multiple Department of Defense agencies.



MPC sponsored research volume, spanning FY2006–FY2015



MPC major sponsors 2015



MPC academic affiliations 2015

Overview and Outlook

Research volume for FY2015 was approximately $14.1 million, a reduction of 9% from FY2014. This is still significantly above the 10-year low of $8 million in FY2009. The reduction in expenditures can be attributed primarily to the transition of Professor Gang Chen's S3TEC DOE program from MPC to Mechanical Engineering. Fortunately, Professor Chen's proposal for a five-year renewal of his program with DOE was successful; however, subsequent to his appointment as Mechanical Engineering department head, it was decided to move administrative oversight for the program to that department, resulting in a loss of $3.2 million in MPC's volume. Setting this significant event aside, the MPC had a good year. The Skoltech Center for Electrochemical Energy Storage completed its first year of full funding (approximately $1.3 million), and the Center for Integrated Quantum Materials was initiated and will have a steady-state funding level at MIT of about $1 million.

We anticipate that our research volume will not significantly change in FY2016 and that there might be a small increase. The Skoltech Center for Electrochemical Energy Storage is budgeted for continuation with level funding, and Skoltech has expressed strong support for the center. However, Skoltech's budget is itself subject to some uncertainty, leading to the possibility of changes in the center's funding from this source. MPC's education and workforce development activity in the AIM Photonics program is budgeted for about $1.3 million per year. New faculty in DMSE (Allanore, Olivetti, and Hu) and Physics (Fu, Jeremy England, George Checkelsky, and Cisse) have rapidly growing research programs, and a number of senior faculty have proposals submitted or under development for major expansions of their current programs.

Over the past year, we have continued to expand the services we provide to the MIT and external communities. For example, we are providing more extensive and customized financial services to faculty members and creating and designing new equipment booking and billing databases and websites with collaboration tools.

MPC activities such as Materials Day and the summer intern program are made possible through funds received from members of the MPC Industry Collegium. The collegium membership has grown to 10 companies over the past year, a result of stronger collaboration and effort working with ILP, faculty, and visiting companies. We continue to support strong ties with ILP, which is the source of the majority of our collegium members. The recent support of ILP's members in China is an example of this effort, which leads to both new opportunities and new challenges for extending our mission in advancing materials science with industry on a global basis. Reinventing and growing the collegium will continue to be a high priority for the center in the coming year.

The building of MIT.nano will have a hugely beneficial impact on the materials research community at MIT. This is probably the most important event for the materials community in the last several decades. MPC is working closely with associate dean for innovation Vladimir Bulović and others to develop strategies through which the activities of MPC, MIT.nano, and other centers can be integrated to optimize benefits for all members of the MIT community. This period provides an opportunity for significant evolution of the modes and mechanisms of the center's operation.

MPC looks forward to continuing its work with individual faculty members and teams of faculty to develop and support new interdisciplinary research programs. As always, the center will continue to search for new ways to interact with industry in order to create collaborations that promote two-way exchanges of expertise and lead to the development of new materials and processes that provide sustainable improvements in quality of life worldwide.

Carl V. Thompson
Director
Stavros Salapatas Professor of Materials Science and Engineering