

## KNOWLEDGE TRANSFER TO INDUSTRY AND OTHER SECTORS

CMSE has a long-standing history of promoting collaboration with, and knowledge transfer to, industry. The many excellent CMSE-supported graduate students and postdocs who leave MIT to work in industry represent an important vehicle for knowledge transfer. By emphasizing team-based, interdisciplinary research within the IRG groups, students and postdocs are trained in a mode that is critically important to meeting the complex, fast-moving challenges of industry. Indeed, the education and research programs at MIT have a proven track record for producing many industrial leaders.

CMSE works effectively with a number of MIT industrial programs and centers to facilitate the transfer of the fundamental knowledge generated within the MRSEC program to industry. MIT's Materials Processing Center (MPC) and Industrial Liaison Program (ILP), for example, work cooperatively to connect industry to the research carried out within the MRSEC program. About 200 multinational companies belong to the ILP, and approximately twenty MIT industrial liaison officers who help to make connections to CMSE research serve these companies. The mission of the MPC, of which Prof. Carl **Thompson** is director, is to promote collaborations with industry and to foster the exchange of knowledge and the development of new knowledge. To accomplish this mission, the MPC runs an industrial collegium that engages in such activities as technology benchmarking, the organization of industry-focused working groups and the establishment of consortia. MPC currently has 20 member companies in the MPC Industry Collegium and 10 member companies in the Microphotonics Center Consortium, plus 20-30 firms directly involved in its Technology Working Groups. MPC also maintains informal contact with more than 200 companies.

### Summary of Important Activities and Events during this Funding Period

CMSE has strengthened its involvement in one of the showcase MIT materials events, the annual "Materials Day at MIT" organized by the Materials Processing Center; CMSE now jointly sponsors this symposium and contributes significantly to its technical program. One important objective of this event is to connect MIT materials research to managers and researchers from industry and government laboratories. The title of this year's "Materials Day at MIT" event was "Nanostructure to Infrastructure to Sustainability." CMSE speakers and moderators included Professors **Irvine**, **Thompson**, and **Van Vliet**. The meeting was attended by approximately 70 registered guests from industry, government laboratories, hospitals, MIT, and other universities, as well as by an additional 25-30 researchers and students from MIT who joined throughout the day on a walk-in basis. Companies represented included 3M, Analog Devices, Bose Corp., Corning, Hewlett-Packard, Lockheed Martin, Lord Corporation, Nokia, Raytheon, Saint-Gobain, Shell Oil, and Toshiba. The capstone poster event included posters from CMSE students and others from the MIT materials science community; students from two CMSE-supported research groups won prizes for best poster: "Functional Polyelectrolyte Multilayer Patches on Living Lymphocytes" by Fernando Vasconcellos and Albert Swiston of the **Cohen/Rubner** group; and "Multifunctionalized Electrospun Materials for Toxic Chemical Protection" by Kevin Krogman of the **Hammond** group. The poster session was judged by a panel of judges from MPC's Advisory Board.

CMSE continued collaboration with the Department of Materials Science and Engineering and the Materials Processing Center to bring a wide variety of speakers from outside of MIT to meet with faculty and students, and to deliver lectures to which the entire MIT community was invited. These lectures typically drew audiences of 60-100 people. *In Fall 2008*: Paul McEuen (Cornell MRSEC), Taeghwan Hyeon (Singapore National U. and Cornell), Ken Sandhage (Georgia Tech), Chekesha Liddell (Cornell MRSEC), and Izabela Szlufarska (U. Wisconsin MRSEC). *In Spring 2009*: Monica Olvera de la Cruz (Northwestern MRSEC director), Frans Spaepen

(Harvard MRSEC), David Seidman (Northwestern MRSEC), Matt Doty (U. Delaware), and David Smith (Duke).

MRSEC-supported faculty presented an overview of their research in two ILP-sponsored conferences: 1) 2008 MIT Research and Development Conference (M. **Buehler**, K. **Van Vliet**, G. **Ceder** and F. **Stellacci**); 2) 2008 MIT in Japan Conference (D. **Nocera**, S. **Leeb**). These conferences were attended in total by more than 450 representatives from U.S. and foreign companies including 3M, L-3 Communications Corp, Raytheon, Hitachi, Ltd., Nissan Motor Co., Ltd., Sharp Corporation, NEC Corporation, and Canon Inc.

To promote knowledge and technology transfer, the MIT ILP also arranges meetings between MIT faculty and members from industry (both domestic and foreign). These meetings are typically hourly meetings held at MIT, full or half-day meetings at the company, or faculty briefings to a small group of technical managers from a single company or an industrial consortium. Such meetings often result in new research partnerships, new product or process development and/or consulting arrangements, all of which result in the transfer of CMSE fundamental knowledge to industry. In the past six months alone, MRSEC faculty and/or their group members have engaged in at least 40 meetings with representatives from a broad range of different domestic and foreign companies, including visits from industrial representatives, faculty visits to different firms, briefings to company executives, and teleconferences. A partial list of these companies includes Air Liquide, BP Solar, Bekaert, Olympus, Siemens, Eni, Michelin, Bridgestone/Firestone, Sharp, Tata Chemicals, Ciba Specialty Chemicals, Pall Corporation, Bosch, Hitachi, and Honda. Director **Rubner** gave an overview of all MIT-MRSEC research at two of his industry meetings: during a videoconference with DSM of the Netherlands, and at an executive briefing with Johnson & Johnson.

CMSE-supported work was on display at the third annual "Energy Night" poster session, sponsored by the MIT Energy Club. This student-organized event showcases MIT's most exciting work in energy: research, start-ups, and campus initiatives. Students from the **Ceder** group presented a poster entitled "Computational Materials Design for Photovoltaic and other Energy Applications," and students from the **Hammond** group presented a poster entitled "Layer-by-Layer Assembled Proton Exchange Membranes for Fuel Cells." Both posters highlighted MRSEC-sponsored research.

MIT's Technology Licensing Office (TLO) is kept aware of new discoveries emanating from CMSE research and helps researchers file patents and issue licenses. Since the start of the new grant period, five new patents have been issued and eight new patent applications/provisional patents are pending that are related to the MIT MRSEC. In addition, there are currently 21 active industrial, academic, and governmental licenses of CMSE-patented research (including two new licenses from the current grant period).

Another important mechanism for knowledge transfer is the creation of new companies and businesses (and related jobs). Currently active CMSE-related companies that were started by MRSEC faculty, students or post-docs include OmniGuide Inc., LumArray, Luminus Devices Inc., QD Vision, and three recent start-ups: Kateeva, WiTricity Corporation, and Svaya Nanotechnology. These various companies were founded to develop novel devices and components based on discoveries made within the MRSEC program and funded, in several cases, exclusively through NSF. Additionally, Nanosys and Quantum Dot Corporation (bought by Invitrogen) are companies whose technology platform is based in part on CMSE-supported fundamental research.



Kateeva was started in 2008 by Professor Vladimir Bulovic (supported by the previous MRSEC award) and several of his MRSEC-funded group members, along with MIT Professor Martin Schmidt. The mission of Kateeva is to commercialize a new technology that could radically change manufacturing for the flat panel display industry, and enable displays that are thinner, brighter, lighter, more vivid, more power efficient, and less expensive than what is possible today. The company is located in Menlo Park, CA.



WiTricity Corporation was founded in late 2007 to commercialize a new technology for wireless electricity, pioneered by MIT Professor Marin **Soljačić**. His theories of wireless electrical power transfer were validated experimentally and published in two 2007 papers that were co-authored by MRSEC-supported student Aristeidis Karalis of the **Joannopoulos** group: "Wireless Power Transfer via Strongly Coupled Magnetic Resonances," *Science* 317(5834), 83-86 (2007); and "Efficient Wireless Non-Radiative Mid-Range Energy Transfer," *Annals of Physics* 323(1), 34-48 (2007). The company is located in Watertown, MA.

The newest CMSE-related start-up, Svaya Technologies, was founded by Prof. **Hammond** and colleagues in September 2008.



This Boston-area company will commercialize a new thin film manufacturing process that is more flexible and scalable than existing methods. The technology is based on an aqueous solution self-assembly process that emerged, in part, from layer-by-layer research that was pioneered by an IRG funded during the previous MIT MRSEC grant (IRG-II).

We estimate that total direct job creation by the seven most closely CMSE-related companies is about 340 jobs to date.

### Research Collaborations of IRGs

The Center's MRSEC-supported faculty enjoy a high level of outside collaboration. During this funding period there were 10 industrial collaborations, 23 collaborations with outside academic researchers, and 11 collaborations with government laboratories and agencies that were MRSEC related. In addition, a number of CMSE faculty members supervised students in departmental co-op programs that carry out research projects in a wide variety of industrial laboratories. Specific IRG and initiative collaborations are summarized below:

#### IRG-I Collaborations:

This research team has excellent connections to industry and national laboratories. **Shao-Horn** works with materials specialist *R. Pearlstein* at Air Products, with fuel cell expert *R. Rajendran* at DuPont, with electrocatalysis and fuel cell expert *H. Nakanishi* at Toyota, and with electrocatalysis expert *F. Wagner* at General Motors. **Shao-Horn** also collaborates with *R. Adzic* at Brookhaven National Lab for XANES/EXAFS experiments; with *P.J. Ferreira* (UT-Austin) on micro- and nano-systems covering design, fabrication, and simulation, with and *L. Allard* (Oak Ridge National Lab) on Cs corrected STEM imaging of nanoparticles. In addition, she regularly uses the Spring-8 radiation facility in Japan.

**Ceder** works with researchers at Lawrence Livermore National Laboratory through the Batteries for Advanced Transportation Technology program (BATT) of DOE. He also continues a long-standing collaboration with *C. Grey* (SUNY) on the local characterization of Li battery materials via NMR and PDF techniques and with *E. Garcia* (Purdue) on the mesoscale modeling of transport in battery electrodes. **Ceder** has initiated an exciting new collaboration with *S. Levasseur* at Umicore in Belgium for synthesis and testing expertise.

**Marzari** collaborates with *A. Wieckowski* (UIUC) on the vibrational characterization of adsorbates on nanoparticles; and **Thompson** works with *M. Burns* at the Rowland Institute

(Harvard) on templated dewetting to form metallic nanoparticle arrays, and with *W.-K. Choi* (Nat. U. of Singapore) in the development of new techniques for fabrication of silicon and metallic nanostructures.

#### **IRG-II Collaborations:**

**Van Vliet** collaborates with *A. Balazs* (U. Pittsburgh) on the design and analysis of analytical and computational simulations of Belousov-Zhabotinsky gels. **Buehler** collaborates with *A. van Duin* (Penn State) and *W.A. Goddard III* (Caltech) on the development and application of ReaxFF force fields, and with *B. Moran* (Northwestern Univ./KAUST) on developing nonlinear elastic finite element continuum models for soft materials.

#### **IRG-III Collaborations:**

This group collaborates as a whole with *H.A. Stone* (Harvard University) on the theoretical study of capillary breakup phenomenon of nano-size features in multimaterial fibers; with *A.F. Abouraddy* at University of Central Florida to study the synthesis and analysis of coherent superpositions of optical states in hollow-core photonic band gap fibers; and with *M. Loncar* at Harvard University to investigate photonic crystal techniques for enhancing nonlinear optical Terahertz generation. **Ippen** works with *P. Juodawlkis* at MIT Lincoln Laboratory to analyze optical nonlinearities in semiconductor structures for experimental studies.

#### **Initiative-I Collaborations:**

**Bawendi** continues a successful collaboration with *R. Jain* at Harvard Medical School/Mass. General Hospital on *in-vivo* monitoring of tumor microenvironments. **Irvine** will work with *C. Wu* (Harvard Medical School/Dana Farber Cancer Institute, Cancer Vaccine Center) to explore the use of nanoparticles for delivering proteins and oligonucleotides into immune cells for vaccine screening and vaccine delivery. **Stellacci** collaborates with *Y. Astier* (U. of Lisbon) to create phosphorylcholine lipid bilayers.

**Rubner** and **Cohen** (IRG-II) continue long-standing collaborations with *D. Banerjee* at Toyota on the development of structural color pigments for car paint, with *H. Zheng* (Essilor Corp.) on the development of anti-fog coatings for eyewear, with *K. Douzinas* (Bayer Corp.) on functional coatings for use in architectural elements, with *P. Schwachulla* (Karl Storz, Germany) on anti-fog coatings for endoscopic lenses, with *Q. Wang* (Agilitron) on a NASA program to create UV-anti-reflection coatings for space telescopes, and with *M. Beppu* (U. Estadual de Campinas, Brazil) on biological polymer fabrication.

#### **Initiative-II Collaborations:**

**Hudson** collaborates with *G. Gu* (Brookhaven National Lab) and with *H. Ikuta* (Nagoya University, Japan), both of whom grow single crystal high temperature superconductors suitable for study by scanning tunneling microscopy. **Lee** will collaborate with *A. Keren* (Technion, Israel) for muon spin resonance measurements and with *H.B. Chan* (U. Florida) for MEMS-based susceptibility measurements. **Lee** also performs x-ray scattering experiments with *G. Srajer* at Argonne National Laboratory and with *J. Hill* at Brookhaven National Laboratory. **Lee** and **Nocera** conduct neutron scattering experiments with *S.E. Nagler* at Oak Ridge National Laboratory, and with *J.W. Lynn* at the NIST Center for Neutron Research. **Nocera** works with *Q.Z. Huang* (NIST), *T. Yildirim* (NIST) and *A.B. Harris* (U. Penn) for spin-wave calculations for the kagome lattice.

**Seed Collaborations:** **P. Jarillo-Herre** works with *C. Marcus* (Harvard) to investigate carbon nanotubes and graphene-based microstructures; **S. Gradečak** collaborates with *Y. Li* (UC Santa Cruz) on nano-photonics and electronics.