Research Laboratory of Electronics

The Research Laboratory of Electronics (RLE) was founded in 1946 following the ground-breaking research its predecessor conducted leading to the development of ultra high hrequency tadar, changing the course of World War II. Cognizant of its rich history and focused on maintaining its position as MIT's leading interdisciplinary research organization, RLE fosters a stimulating and supportive environment for innovative research. RLE provides visionary leadership, vibrant intellectual communities, and superior administrative services. Through strategic deployment of resources, RLE offers a supportive environment for achieving excellence in research and education. RLE faculty are encouraged to engage in entrepreneurial interdisciplinary research initiatives.

The lab is experiencing rapid and robust growth. Since fiscal year 2007 the lab's research volume has increased by 50%, making it one of the Institute's fastest growing organizations. With a fiscal year 2012 research volume of $46.8 million representing an 8% increase over FY 2011, RLE manages over 200 active research projects and services over 70 principal investigators. In FY 2012, RLE included 300 graduate students (225 of whom are research assistants) and 133 undergraduates working in various labs.

RLE recently created an endowment funded by proceeds from high definition TV intellectual property royalties that will help fund discretionary activities in the years ahead.

Major research funding is provided by the National Aeronautics and Space Administration, Department of Defense agencies, the Department of Energy, the National Institutes of Health, and the National Science Foundation. In addition, numerous projects are funded through industry and private foundations.

Academic year 2012 saw many awards, recognitions, and milestones for RLE investigators, and striking progress in research associated with groups and various educational initiatives begun within the past several years.

Atomic Physics

Research in atomic physics at RLE encompasses an investigations in ultracold atoms, quantum condensed gases, and atom optics. New methods are being developed for manipulating and probing Bose-Einstein condensed atomic gases and exploring ultracold interactions and collision dynamics in bosons and fermions. Additional work focuses on atom lasers, atom interferometry, atom waveguides, surface physics, quantum reflection, many-body physics in lower dimensions, plasmas, and electromagnetics.

The focus of professor Wolfgang Ketterle's research is on the study of the properties of bosonic and fermionic quantum gases. In addition, the group uses ultracold atoms to realize new forms of matter with strong interactions and strong correlations. In this way, it performs quantum simulations of simple Hamiltonians. Quantum degenerate gases are novel systems for studying many-body physics phenomena including phase transitions, superfluidity, and vortices. The new focus of the group's program is quantum magnetism, i.e. the ordering of spins. Interesting results include Bragg scattering as a probe of atomic wavefunctions and quantum phase transitions in optical lattices. The group has recently observed Bragg scattering of photons from quantum degenerate 87Rb atoms in a three-dimensional optical lattice demonstrating how Bragg scattered light directly probes the microscopic crystal structure and atomic wavefunction (H. Miyake et al., Physical Review Letters 107, 175302, 2011). Possible applications of the group's work include coherent atom sources based on Bose-Einstein condensation that may replace conventional atomic beams in demanding applications such as atom interferometry; precision measurements; future atomic clocks (which provide the time and frequency standard); matter wave microscopy; and the creation of microscopic structures by direct-write lithography. In addition, ultracold gases of bosonic and fermionic atoms are quantum degenerate gases, which have properties different form the quantum liquids helium-3 and helium-4. Therefore, it is now possible to study macroscopic quantum phenomena in a new regime.

The research of professor Vladan Vuletic focuses on how quantum correlations (entanglement) in quantum mechanical systems can be used to overcome various measurement limits and to improve atomic sensors or atomic clocks. He is also interested in exploring the possibility of building a quantum computer. Finally, Professor Vuletic is interested in unresolved questions in quantum mechanics, the measurement process, and quantum correlations between distant particles (non-locality). The realization of strong nonlinear interactions between individual light quanta (photons) is a long-standing goal in optical science and engineering, being of both fundamental and technological significance. In conventional optical materials, the nonlinearity at light powers corresponding to single photons is negligibly weak. Using two approaches, his group has demonstrated a medium that is nonlinear at the level of individual quanta, exhibiting different transmission characteristics for one and for two photons. In one approach, a vacuum field inside an optical resonator is used to slow a photon to a speed of only 2000 m/s. The paper concerning these results was published in Science (Tanji-Suzuki, H., et al., vol. 333, 6047, 1266–1269, 1208066, Sept 2011) and discussed in separate articles in Science, Nature Photonics, Physics Today, and several other journals. Professor Vuletic's group has demonstrated an optical medium that exhibits strong absorption of photon pairs while remaining transparent to single photons. The quantum nonlinearity is obtained by coherently coupling slowly propagating photons to strongly interacting atomic states. The work was published in Nature (Peyronel, T., et al, vol. 488, 57–60, 11361, Aug 2012.) Both systems described above may enable quantum gates between photons for all-optical quantum computation, or an optical transistor that is operated with a single control photon. These methods will be used in the future to implement small optical quantum computers, and to improve atomic clocks and other measurement devices beyond the so-called standard quantum limit that is associated with the measurement process in quantum mechanics.

Professor Martin Zwierlein's group in experimental atomic physics uses atomic gases at ultralow temperature as a universal test-bed for condensed matter and nuclear physics. The interactions between the atoms in these gases can be made as strong as quantum mechanics allows. The group is running three experiments, all focusing on the study of fermions, particles with half-integer spin like electrons. Fermions have to obey the Pauli principle, the constraint that no two fermions can occupy one and the same quantum state. This principle lies at the heart of the periodic system of elements and it explains the stability of neutron stars against gravitational collapse. However, when fermions strongly interact, theoretical predictions become extremely difficult. Experiments are needed to uncover how nature deals with this intricate problem. This year, Professor Zwierlein's group directly measured the equation of state (the relation between pressure, density, and temperature) of such strongly interacting Fermi gases across the superfluid phase transition. For the first time, they observed the superfluid transition directly in the thermodynamics of the gas. The result was published in Science (Ku, M. J. H., et al., vol. 335, 6068, 563–567, 1214987, February 2012).

Additional research carried out in collaboration with University of Massachusetts at Amherst researchers corroborated the excellent matching between theory and experiment. The joint work was published in Nature Physics (Van Houcke, K., et al., vol. 8, 366–370, 2273 March 2012.) Additionally they have begun studies of strongly interacting Fermi gases in lower dimensions and they are able to follow the evolution of fermion pairing from three to two dimensions by confining the atoms more and more tightly along one direction. Their results were published in Physical Review Letters (Sommer, A. T., et al., vol. 108, number 4, 045302, January 2012) and featured in the American Physical Society's journal Physics. The work is likely to produce significant insights into future efforts leading to quantum computation. Ultracold atomic gases represent essentially the basic building blocks of many-body theory. The group can model bosons and fermions in a clean and perfectly controllable environment. Interplay between theory and experiments thus allows novel insights into a vast variety of physics problems, ranging from condensed matter physics to nuclear and astrophysics. In condensed matter physics, for example, the mysteries of high-temperature superconductors, colossal magnetoresistance materials, spin systems, and quantum magnetism are not well understood. In nuclear physics, where one aims to recreate the first split-second of the universe, new forms of matter are found, the so-called quark-gluon plasma. This strongly interacting soup of quarks and gluons shares properties with the group's strongly interacting Fermi gas. As a third example, physicists try to understand the nature of distant neutron stars, extremely dense remnants of a star slightly heavier than our sun, but only ten miles in diameter. Despite the immense difference in density and scale, neutrons are fermions just as the atoms in Professor Zwierlein's experiments, and it is possible to increase the interactions between atoms to be as strong as those between neutrons in a neutron star. From a table-top experiment, the group can thus learn about the equation of state of distant neutron matter.

Circuits, Systems, Signals and Communications

Research in this area spans a range of activities over all aspects of electronics, including structures, devices, and circuits; analog and digital systems; microelectromechanical (MEM) and bioMEM devices; nanotechnologies; numerical and computational simulation and prototyping; biologically inspired systems; digital signal processing; advanced telecommunications; medical imaging; and the exploration of fundamental issues in wireless networking and devices.

For almost five decades, the Digital Signal Process Group in RLE has been at the forefront of the exciting field of signal processing. Their current focus is on the development of signal processing algorithms with the view that signal processing is a technology that spans a host of application areas. While the development of meaningful and potentially useful algorithms is done best with attention to potential applications, the commitment in current research is to the algorithms in general rather than to specific applications. Consistently, the group has successfully looked to application areas such as speech and image processing, sensor networks, communications, and radar and sonar, to name a few.

Much of the research over the years has been involved in the development of algorithms in traditional areas such as signal modeling, quantization, parameter estimation, sampling, and signal representations. The group has also successfully explored unconventional directions such as algorithms based on fractal signals, chaotic behavior in nonlinear dynamical systems, and the exploitation of solitons associated with particular classes of nonlinear wave equations. These creative directions can be categorized initially as "solutions in search of problems." However, typically the group has been able to eventually identify potential applications for these solutions. In many cases, these unique projects have led to patents and have been incorporated into real world systems.

Another approach the group has taken in developing new algorithms has been to look to nature for inspiration and as a metaphor for new signal processing directions. Work on chaos, solitons, and fractals falls in this category to a certain extent. More recently, studying quantum mechanics as a parallel has led the group to the development of a variety of new algorithmic frameworks, which researchers describe as Quantum Signal Processing. In a similar vein, they are studying signal processing in cell biology and its potential as an analogy for new signal processing algorithms.

Research in professor Vincent Chan's team focuses on contemporary challenges in heterogeneous networks and communication systems. The work extends to applications in satellite, wireless and optical communication, and data networks. The objective is to develop the scientific base needed to design data communication networks that are efficient, robust, and architecturally clean. In addition to ongoing work on optical networks, both fiber and free-space, they have established in the last two years a new focus on heterogeneous networks combining fiber, wireless, and satellite systems. Heterogeneous networks must provide agile and economical service delivery in the face of challenges that include rapidly changing communication channel quality, link connectivity, and traffic flows. The biggest challenges come from channels with fast time-varying properties, such as their capacities, and from applications that require timely deadline delivery such as disaster relief and early warning. These scientific investigations are vital to growing the capacity of the Internet by orders of magnitude in the future at lower cost per bit and tighter energy budgets. Professor Chan has spearheaded a major study entitled "Highly Controllable Dynamic Heterogeneous Networking," sponsored by the White House Office of Science and Technology Programs Office together with the National Aeronautics and Space Administration and the National Science Foundation, and aimed at creating a research roadmap for future generations of high-speed networks.

The Digital Integrated Circuits and Systems Group led by professor Anantha Chandrakasan designs and implements various integrated circuits ranging from ultra low-power wireless sensors and multimedia devices to high performance processors. The research spans across multiple levels of abstraction ranging from innovative new process technologies and circuit styles to architectures, algorithms, and software technologies. A key focus of this group is developing energy efficient integrated solutions for battery-operated systems. The group had two major highlights this year. The first is a new energy conversion integrated circuit that captures energy from multiple sources. A paper accepted for publication in the IEEE Journal of Solid-state Circuits (summer 2012), presents the group's recent work on energy harvesting focusing on combining light, heat and vibrations. To reduce board area, the chip uses a time-shared inductor to realize multiple power converters. The chip, suitable for wireless sensor applications including body-worn electronics, uses a variety of techniques to maximize conversion efficiency; for example, it uses a time-based approach for maximum power-point tracking. The chip also uses dual-path architecture to improve efficiency. The second highlight is a low-power biomedical signal processing platform (J. Kwong, et al., IEEE Journal of Solid-State Circuits, vol. 46, no. 7, 1742–1753, July 2011.) They developed an energy-efficient digital processing platform for wearable sensor nodes, designed to support diverse biological signals and algorithms. The platform features a 0.5-1.0-volt 16-bit microcontroller, static RAM, and accelerators for biomedical signal processing. Voltage scaling and block-level power gating allow optimizing energy efficiency under applications of varying complexity. The chip also features a variety of programmable hardware accelerators to support numerous usage scenarios and perform signal- processing tasks using 100-times lower energy than a general-purpose CPU. When running complete electroencephalogram and electrocardiogram applications using both CPU and accelerators, the platform achieves more than an order of magnitude energy reduction compared to CPU-only implementations.

Professor Luca Daniel and his students have been focusing on developing efficient simulation and modeling tools of integrated circuit components and systems. On the simulation side, they have been developing stochastic field solvers for large and complex problems with uncertainties and variations in a large number of parameters. On the modeling side, they have been studying automatic generation of compact dynamical models for linear and nonlinear components and systems, either directly from field solvers, or from available measurements on fabricated prototypes. Their work on developing deterministic and stochastic electrostatic field solvers for capacitance extraction has been receiving lots of attention; several companies are considering integrating their tools in their design flows, including IBM of Armonk, NY; Intel of Santa Clara, CA; and Mentor Graphics of Wilsonville, OR. Technology transfer is happening via summer internships and visits. Other research centers such as the Politecnico di Torino in Turin, Italy, are running the Daniel group's parallel algorithms in their multiprocessor machines achieving great efficiencies (90% on 80 machines).

Professor Daniel and his students have also obtained good results from their tool that automatically generates models for film bulk acoustic resonators , based on measurements produced in collaboration with the group of professor Duane Boning at the Microsystems Technology Laboratories. In addition, they have been trying to apply their fundamental expertise and techniques in simulation and modeling of integrated circuit interconnect to the biological and biomedical fields. Their project on simulation of arterial blood flow, in collaboration with Merck Pharmaceuticals is showing a promising application. Design and optimization of novel radiofrequency (RF) nanoelectromechanical (NEM) resonators such as resonant body transistors require modeling across multiple cross-coupled domains, including mechanical (distributed stress and elastic wave models), electrical (semiconductor devices and RF small signal models), and thermal. To address this need, Daniel's group has developed an algorithm that automatically generates compact models for NEM resonators. The resulting compact models allow the circuit designers to run circuit-level DC, transient, AC, and periodic steady state analyses using any commercial circuit simulator. The models are parameterized. Values for the model coefficients are calibrated using measurements from NEM resonator devices. Their algorithm guarantees that when circuit designers arbitrarily change values for the device parameters, the instantiated models will never cause numerical instabilities and convergence issues when connected to other device models and circuits within the circuit simulator. Their results show high quality fit to the measured data even in the presence of noise and spurious resonant peaks.

In carbon-related work, the activities of professor Mildred Dressselhaus's group were mostly focused on studying the Raman spectra of graphene as a function of both an externally applied gate voltage to vary the Fermi level and laser excitation energy. In bismuth-related work, the group studied the electronic band structure in two-dimensional bismuth with particular focus on regions in the Brillouin zone near the Dirac points that they located. In thermoelectric materials, they studied how modulation doping could be used to enhance thermoelectric performance. In graphene, they found that renormalization effects were necessary to explain the observed Raman spectra in the detail of their experimental accuracy. In bismuth, the discovery of these Dirac points will next be explored in connection with the effect they may have on the performance of these materials in thermoelectric applications. In thermoelectric materials research, the modulation doping work will be studied in more detail regarding thermoelectric applications.

The work of professor Vivek Goyal spans several areas of signal processing and information theory. Successful work continues in a variety of areas, including magnetic resonance imaging; optimal decision making under a variety of constraints, especially those related to human cognitive limitations; and design of information representations for human perception and for networks that combine data acquisition with computation. The most prominent lines of work provide novel estimation algorithms (e.g., providing large improvements over the state-of-the art in reconstruction from quantized data samples) and radically new methods for using time-resolved sensing in optical imaging..

In the previous year, Professor Goyal's group introduced the concept of diffuse imaging and collaborated in the first experimental demonstration of optical imaging using only diffuse reflections and no direct line of sight—figuratively, using a matte surface as if it were a mirror. This year, the researchers have introduced a way to think about optical imaging that subsumes diffuse imaging; they call it space-from-time imaging (SFTI) to express that, whether or not illumination and sensing are diffuse, the spatial correspondences that are normally provided by focusing optics can instead be created computationally from time-resolved sensing of the response of a scene to spatiotemporally-varying illumination. SFTI produces new inverse problems that can take a variety of forms depending on the availability of prior knowledge and the parameterization of what is unknown. Diffuse imaging the reflectance pattern on a scene with known geometry corresponds to a simple example of SFTI that yields a linear inverse problem. Problems of geometry recovery through SFTI are more challenging and rewarding; the proof-of-concept implementations described below are the first to achieve certain capabilities and promise significant technological impact. Estimation of a vector from quantized linear measurements is a common problem for which simple linear techniques are suboptimal, often greatly so.

Professor Goyal's group introduced message-passing de-quantization (MPDQ) algorithms that greatly outperform all algorithms in the literature for estimation when the quantization is regular. In addition, MPDQ is the first tractable and effective method for high-dimensional estimation problems involving non-regular scalar quantization. All previous algorithms have complexity exponential in the vector length, whereas the Goyal group's is quadratic. Opening up the possibility for practical use of non-regular quantization could have profound impact on data acquisition. The results show that non-regular quantization can greatly improve ratedistortion performance in some problems with oversampling and some with undersampling combined with a sparsity-inducing prior. The potential for space-from-time imaging applications is enormous. Professor Goyal's group is working on ways to implement the central ideas efficiently, with the eventual aim of bringing 3D acquisition capabilities to smart phones at low cost and power. At the same time, the group is also exploring the synergistic combination of its techniques with the conventional RGB (red, green, blue) imaging that is already available on all phones. They have already developed a very simple prototype to demonstrate that cheap omnidirectional illumination and two cheap omnidirectional sensors can be used for coarse localization by time-of-flight. Work is under way to fuse this with ordinary photographs to achieve high-resolution depth estimation. Professor Goyal envisions the ability to implement this technique in mobile devices for virtual reality and gestural interface applications.

Professor Jae Lim's group is involved in the development of video compression methods. Video compression is used extensively in reducing the required bandwidth in video communication systems and in reducing the required storage in the same systems. The group's application focus is on improving digital TV systems. Significant results from this year include development of new transforms for video compression systems. These have the potential to be used for the development of new video compression systems and for efficient transmission of 3D TV signals.

Professor Muriel Médard leads a highly collaborative research group with research collaborations at MIT that include the Computer Science and Artificial Intelligence Laboratory, the Laboratory for Information and Decision Systems, the Microsystems Technology Laboratories, and MIT Lincoln Laboratory. Other research partners include Aalborg University; Alcatel-Lucent; American University of Beirut; the Australian National University in Canberra; BAE Systems in London; Boston University; the Budapest University of Technology and Economics; the California Institute of Technology; Eurecom in Biot, France; KTH in Stockholm, Sweden; the National

University of Ireland at Maynooth; Orange/France Telecom in Paris; Raytheon BBN; Rutgers University; Stanford University; the Technical University of Munich; Technicolor; Texas A&M University, the University of Porto in Porto, Portugal; Xidian University in Xi'an, Shaanxi, China; and the University of Waterloo in Waterloo, Ontario, Canada. Its central theme is communications, with a special emphasis on new practical and theoretical developments in the area of network coding. Achievements during the past year include both theoretical and practical work in developing network coding techniques for wireless cellular systems, new analysis and demonstrated code for providing virtual coded transmission control protocol, new fundamental results in the area of throughput-delay tradeoffs, new fundamental results in the area of low-signal-to-noise-ratio wireless capacity, and new theoretical and practical advances in network coding for body area networks.

Professor Vladimir Stojanovic's Integrated Systems group focuses on development of methodology, circuits, and system techniques for both traditional Complementary MOS (CMOS) with copper interconnects and emerging technologies (e.g., nanoelectromechanical switches and silicon-photonic interconnects). In the push to accelerate the evaluation and adoption of promising emerging technologies, they have had several important breakthroughs in demonstrating larger scale functional systems with both the nanoelectromechanical (NEM) switch-based circuits and silicon-photonic interconnects integrated within a larger electronic integrated-circuit test-platform. Using devices from Tsu-Jae King Liu of the University of California, Berkeley, the Integrated Systems group designed and demonstrated the largest-ever working NEM relay circuit—a 100-relay multiplier block, published at Asian Solid-State Circuits Conference in November 2012. Together with Elad Alon (of the University of California, Berkeley) and Dejan Markovic (of the University of California, Los Angeles), Professor Stojanovic's group designed the world's first relay-based microprocessor (12,000 relays), which is being fabricated by both Texas Instruments and UC Berkeley. This year his group also designed and demonstrated the largest working relay circuits (46 devices) with the smallest relay microelectromechanical (MEMS) devices ever built (16um x 16um), in a relay process transferred from UC Berkeley to SEMATECH of Albany, NY.

Also this year, Professor Stojanovic and his students have made several important breakthroughs in bringing silicon-photonic interconnects one step closer to commercial CMOS foundries. In particular, they have partnered with Micron Technologies of Boise, ID, to bring the silicon-photonic platform into dynamic random-access memory (DRAM) chips, and have already gotten first results from initial test chips, demonstrating that low-loss photonic components can be fabricated in Micron's DRAM process flow. Based on these results—and their architectural and circuit feasibility studies showing revolutionary potential of this technology to future processor-memory communication — they have started a large four-year Defense Advanced Research Projects Agency (DARPA) program to develop this technology, leading the team in partnership with Micron, UC Berkeley, and the University of Colorado at Boulder. This year, the team has fabricated a full photonic link in Micron's process (currently under test), and has demonstrated world's first monolithically integrated electronic-photonic circuit in 45nm CMOS silicon on insulator process (used in cutting-edge IBM processors and servers). The work was published in Optics Express (Orcutt, J. S., et al, Optics Express, 20, 11, 12222–12232, May 2012).

Professor Jacob White joined the Electrical Engineering and Computer Science (EECS) administration as a coeducation officer in July 2011 and since then his research focus has shifted to education and curriculum development. He worked with Chris Terman on the browser-based circuit simulation program that is an integral part of 6.002x Circuits and Electronics, and he is working with professor Collin Stultz and associate professor Elfar Adalsteinsson on a new introduction to medical technology that includes a table-top magnetic resonance imaging system (MRI), and developing curriculum for the MIT- Skolkovo Institute of Science and Technology program and for the MIT-Singapore University of Technology and Design program. Professor White's research in numerical techniques has shifted focus, and most of the effort is in areas associated with medical technology and systems biology, and includes work on MRI and electrical impedance-based neurology.

Detailed analysis of the electromagnetic fields in MRI plays an important role in patient safety, as high electric fields proximate to sensitive tissues can cause damage. Faster numerical techniques can be enabling for MRI in two ways. Reasonably fast simulation can be used in MRI design optimization by making it possible to assess a variety of alternative coil designs and excitation strategies. But if 3D field analysis for a given patient were possible in seconds, it could be used to generate patient-specific excitation strategies, thus improving patient safety while enhancing image quality. In collaboration with Laurence Wald (at Massachusetts General Hospital, Adalsteinsson, and associate professor Luca Daniel, White has worked on accelerating MRI simulation. Their joint work on numerical Greens function techniques has led to reductions in 3D simulation time from hours to minutes.

Professor Gregory Wornell's research has centered on algorithms and architectures for millimeter-wave imaging, reliable wireless communication, quantum optical communication, secret-key distribution, and advanced brain-machine interfaces. In the area of millimeter-wave imaging, motivated by a variety of emerging commercial applications, his group has been developing new techniques for reducing by orders of magnitude the number of antenna array elements required for high-resolution imaging. The new architecture is based on the use of what researchers refer to as multi-coset arrays, and exploits intrinsic properties of the imaging environment. In the area of reliable wireless communication, they have pioneered a practical and efficient family of rateless codes for communication over unknown time varying channels, as arises in a variety of mobile applications. Their new codes are based on the use of an advanced communication technique referred to as super-Nyquist signaling. As an initial application, the new codes are candidates for use in the US Navy's next-generation underwater acoustic modems and were experimentally validated in the KAM-11 experiment in the Pacific Ocean off Hawaii in 2011.

In the area of quantum optical communication, Professor Wornell's group has developed new spatial-pulse position modulation (PPM) methods for efficient multi-mode communication in the low photon number regime, and for quantum secret-key distribution, they have developed new secure protocols based on a novel PPM-parsing methodology. The new protocols are being experimentally verified. Finally, in the area of brain-machine interfaces, the researchers have demonstrated the viability of concurrent architectures for enabling enhanced motor function capabilities. In particular, the group built a real-time system that is able to reliably and simultaneously decode all the elements of a sequence of planned motor goals, in advance of movement, from measured neural activity in the pre-motor cortex of rhesus monkeys.

Energy, Power and Electromagnetics

This research theme comprises work in excitonics, studies in the absorption and emission of light, solar cells, disordered and low-dimensional materials, complex nanostructures, organic LEDs, nanowires, hybrid organic-inorganic materials, organic structures and devices, power electronics, signal level control circuits and electronics, system identification and control, continuum electromechanics, and high voltage and insulation research.

Professor Marc Baldo is the director of the Department of Energy-sponsored Center for Excitonics, an Energy Frontier Research Center whose principal mission is to supersede traditional electronics with devices that use excitons to mediate the flow of energy. Whereas the former rely on expensive and energy-intensive fabrication processes, the latter are far more suitable for the large-scale production that would be needed to generate sufficient solar cells to have a significant impact on the world energy supply. Professor Baldo's own research program currently centers on solar cells, light-emitting devices, and spintronic switches. A key research accomplishment of the past year is his group's demonstration of a solar cell that generates two electrons for every absorbed photon. The device exploits singlet exciton fission. This is a process that splits one high-energy photon into two lower energy photons.

Dr. Chathan Cooke's research is mainly in two areas: metal-insulator interfaces and energetic electron/photon beam interactions. In metal-insulator interfaces, he has been using a combination of high-resolution ultrasonics to image space-charges near these interfaces and high-sensitivity conduction measurements at high voltages to quantify the terminal currents associated with interface charge accumulations. The primary application is for improved insulation systems in enclosed electric power apparatus and is supported by an industrial sponsor (Toshiba). For energetic radiation work, electron and photon beams are produced by his group's Van de Graaff accelerator facility in the High Voltage Lab. These beams have been applied to develop improved durability of materials for hip and knee implants, working with the Massachusetts General Hospital Harris Orthopedic Biomechanics and Biomaterials Laboratory. Additionally, the beam has been applied for hazardous materials identification by nuclear resonance fluorescence, working with Passport Systems of North Billerica, MA; the Pacific Northwest National Laboratory in Richland, WA; and UC Berkley Physics. This work is mainly supported through the US Department of Homeland Security. Additionally, the beam has been used to calibrate various satellite solar flux detectors, working with satellite instrument companies. Energetic electrons are also implanted into insulators as an effective means to quantify charge transport processes.

Professor John Kassakian's research group has focused on the development of advanced ultracapacitor energy storage devices using carbon nanotubes for electrode structures and the development of very fast algorithms for the calculation of fields and power for three dimensional induction heating applications. During this period, the group provided the demonstration of increased carbon nanotube density through multiple catalytic chemical vapor depositions and the demonstration of field calculations more than 10 times faster than current methods. The carbon nanotube work is applicable to the fabrication of high-density electrodes for lithium batteries, and the fast algorithm is applicable to the calculation of fields in applications other than induction heating.

Professor James Kirtley and his group are building a small-scale microgrid analog simulator with rotating machines (one set simulating a diesel engine generator, one simulating a wind turbine and doubly fed induction generator, and one simply an induction motor load); a simulated solar inverter; and various other static load simulators. At present, the basic framework is built, the diesel engine generator simulator is built, and the researchers are ready to start playing with it. They intend to try to replicate some simulations done by their colleagues at the Masdar Institute of Science and Technology in Abu Dhabi, United Arab Emirates. This is a collaboration with professor Jeffrey Lang; most of the work is being performed by a graduate student. The group has designed a highly advanced permanent magnet motor for electric robot joint actuation. This motor uses a large number of phases so it can tailor the stator current shape to optimally produce torque.

Professor Jeffrey Lang's research focuses on the analysis, design, and control of electromechanical systems with an emphasis on high-performance electrical machine systems, micro/nano-scale electromechanical actuators and sensors , and distributed electromechanical structures. At the 25th annual Institute of Electrical and Electronics Engineers (IEEE) International Conference on micro-electro-mechanical systems in January 2012, professors Vladimir Bulović and Lang, together with their students and research staff, reported a new micro/nanomechanical switch. The switch is based on a piezoresistive composite in which conducting micro/nano particles are suspended in an elastomer. With reference to field-effect transistor terminology, an electric field applied between the gate and source of the new switch causes the composite to compress, thereby modulating the conduction properties of the composite channel between the source and drain. The switch can exhibit an on:off conduction ratio up to 107:1; it can exhibit voltage-controlled conduction with a gain greater than 1 decade per 60 mV, a fundamental limit for silicon-based semiconductor switches; and its contacts are not subject to the usual wear associated with point-contact electromechanical switches.

A significant challenge in vibration energy harvesting is to harvest energy from multi-harmonic or broadband vibrations that may also vary their spectrum over time. Most vibration energy harvesters focus on a stationary single-harmonic vibration. During the past year, Professor Lang and his doctoral student Samuel Chang have shown that active power-electronic loading of a harvester can be used to harvest energy from multi-harmonic vibrations. The total energy harvested is in this case the sum of that which could have been harvested from the individual harmonics through conventional means. Furthermore, when the control of the power electronics is based upon measurements of the vibration source, the loading can be modified to maintain peak harvesting power as the vibrations spectrum varies over time.

Professor Steven Leeb's group has had an exceptional year developing systems for controlling and generating energy. In previous work, the researchers developed new approaches for optical communications using conventional room lighting and inexpensive or "no-cost" modifications to existing fluorescent and solid-state lighting. This work resulted in a patent issued April 3, 2012, Multi-Frequency Dual-Use System, US 8,150,268, which has been licensed to Philips. They also developed a new system for optimizing the energy generated from solar installations by using switch capacitor filters. This approach decouples the utility impedance from the maximum power point tracking control, improving the stability of grid connected photovoltaic arrays. Professor Leeb's group has developed a new technique for sensing occupancy by detecting the ultra-small changes that people make in the static electric fields in a room. They are able to detect femto-farad changes in capacitance in a room-sized space. They received a patent on this technique (US Patent 7,923,936) and have filed for others. The group has developed a new technique for non-contact sensing of current in circuit breakers, speeding the creation of information flow for a "smart grid." They have developed and demonstrated new techniques for using power system monitoring for vibration detection. The group received new funding from the Office of Naval Research based on this work, and is using its techniques to improve the "underway" acoustic signature of US Navy warships.

Professor David Perreault's research has focused on advancing power electronics technology and the use of power electronics to benefit important applications. Major research thrusts have included the development of extreme high-frequency power conversion to attain miniaturization and integration, development of power converters with greatly improved efficiency, and the use of power electronics to benefits applications such as solar photovoltaics and LED lighting. An interesting research result has been the development and validation of a new lossless power combining and outphasing system for radiofrequency (RF) power systems. This technology enables efficient wide-range output power control of RF inverters and power amplifiers. A second valuable result has been the development and validation of a submodule maximum power-point tracking control system for solar photovoltaics. This new, stacked submodule system provides increased power output of photovoltaic systems at low cost. The lossless multi-way outphasing system has applications to many kinds of RF amplifier systems including for industrial processing, medical imaging, rf communications, and power conversion. Application of this technology in RF power amplifiers for cellular communications has been licensed to a startup company, Eta Devices of Cambridge, MA.

Professor Joel Schindall reports that previous research in the 2003–2010 timeframe verified that ultracapacitor energy storage and power density could be significantly enhanced (three times or greater) through use of electrodes coated with vertically oriented carbon nanotubes rather than activated carbon. This research is being commercialized by FastCAP Systems of Boston, MA, which was founded by his previous PhD candidate Riccardo Signorelli. During the current period, Professor Schindall worked with MS candidate Matthew D'Asaro to evaluate whether this technology could be applied to microscopic interlaced nanofingers grown on a silicon substrate. If successful, this technology could increase both the capacity and frequency response of capacitors used in MEMS devices, and provide increased reliability as compared to electrolytic capacitors that are presently the component of choice in this application. In addition, he worked with PhD candidate David Jenicek to better understand the nanotube array growth process, with the goal of further increasing energy storage density more than five times, the capacity of commercial activated carbon ultracapacitors. Professor Schindall's group has successfully demonstrated the growth of devices with higher capacitance than electrolytic capacitors of equivalent size. The researchers also demonstrated that the frequency response is proportional to finger width, which suggests that further increases are possible by utilizing this property. The future application of this work includes the use of interlaced ultracapacitors in MEMS chips for on-chip power conversion and to increase reliability by eliminating the need for failure-prone electrolytic capacitors.

Professor Markus Zahn is engaged in three principal projects. The first is the ABB Project in the MIT Energy Initiative (MITEI), called "Positive and Negative Streamer Initiation and Propagation in Dielectric Liquids," which concerns the use of the COMSOL computer simulation platform. Multiphysics analysis is used to solve high-voltage charge injection and transport in point-sphere electrode geometries that model experimental data taken by the ABB Corporate Research Center in Switzerland, a cosponsor of this research. A second project is the Siemens Project in MITEI, called "Dielectric Materials for New Applications," which uses electric field-induced birefringence (Kerr effect) to measure electric field and space charge distributions in high-voltage stressed parallel plate electrode geometry for various combinations of anode and cathode electrode materials and surface treatments. The goal of the project is to raise the electrical breakdown strength of dielectric materials by choosing electrodes that have bipolar homocharge injection so that positive volume charge forms adjacent to the positive electrode and negative volume charge forms near the negative electrode. Such homocharge distributions have lower electric fields near the electrodes, which allows higher voltage operation without electric breakdown. A third project, "Magnet and Ferrofluid Configurations for Improved Separations of Magnetic and Non-magnetic Materials," involves a new MIT patented method for magnetic separation of magnetic liquid phase/particles from non-magnetic liquid phase/particles. This has been developed for applications such as cleaning up oil spills by separating oil and water liquid phases or by separating magnetic materials from non-magnetic materials in biomedical and microfluidic applications. This work has developed a method using non-uniform magnetic fields generated by edges of permanent magnets for the magnetic separation of magnetic and non-magnetic materials. This work has also developed improvements to magnetic separation using a one-sided magnetic flux configuration, known as a Halbach array, to increase the efficiency of separations.

Professor Zahn's group reported that many of the COMSOL analyses modeled ABB experimental data very well. The Kerr elecro-optic measurements in the Siemens Project have shown that those electrode configurations that resulted in bipolar homocharge injection had higher electrical breakdown strengths. Finally, the group has improved magnetic separation methods for oil/water systems to such an extent that it has the potential to be used in future oil well disasters to limit the damage by quickly and efficiently separating oil from water so that clean water can be returned to the oceans and pure oil with no magnetic nanoparticles can be transported to a refinery for the usual processing. The group has two patent submissions for this process and the postdoc in the group, Shahriar Khushrushai, has received a $40,000 Veolia Postdoctoral Fellowship for this project. The magnetic separation methods developed for ocean oil spills can also be applied to separating magnetic materials from non-magnetic materials in biomedical, microfluidic, and other applications.

Multiscale Bioengineering and Biophysics

Research in this area encompasses thrusts in bio-inspired electronics and neural prostheses for hearing and sight; nanotechnologies and microtechnologies for understanding and manipulating biological processes at the cellular and molecular level; imaging and computational modeling of disease and neuro-anatomical processes; and communication biophysics for language, speech, hearing and haptics, including speech synthesis and recognition, sensory communication in all modalities, and the physiology of auditory perception and speech production.

Professor Polina Anikeeva, who joined the Lab this year, works on novel biocompatible and minimally invasive materials and devices for recording and stimulation of functional neural circuits. Such devices would potentially enable drug-free therapies for neurological disorders such as Parkinson's disease, spinal cord injury and major depressive disorder. Her group has developed a technology that allows the trapping of individual neurons within hollow optoelectronic scaffolds and demonstrates electrophysiological activity of the trapped neurons. The researchers also have fabricated flexible microwire arrays embedded in polymer matrix for future applications in neural recording and stimulation devices. These devices can also be used in characterization of cell development and drug delivery.

The RLE Computational Biophysics Group led by Collin Stultz is focused on understanding conformational changes in biomolecules that play an important role in common human diseases. The group uses an interdisciplinary approach combining computational modeling with biochemical experiments to make connections between conformational changes in macromolecules and disease progression. By employing two types of modeling, molecular dynamics and probabilistic modeling, hypotheses can be developed and then tested experimentally.

Professor Mehmet Fatih Yanik's lab, the High-Throughput Neurotechnology Group, is developing high-throughput high-content technologies for investigating the complex development, function, reprogramming, degeneration, and regeneration of the nervous system. The researchers employ a variety of techniques including micromanipulation, microfluidics, ultrafast optics, advanced microscopy, quantum physics, genetics, and biochemistry. They group also works with a variety of organisms and preparations ranging from C. elegans, zebrafish, and primary rodent and human tissue to human embryonic-stem-cell-derived neurons.

The benefits of so-called parallel excitation systems at ultra-high field continue to be a focus of Elfar Adalsteinsson's group, which is extending these studies to lower fields that capture the mainstay of clinically installed base of MRI systems. Incorporation of parallel transmission for 3-Tesla MRI offers substantial gains for stronger signal and improved management of power deposition with projected benefits for current clinical systems. Incorporation of sparsity in mapping brain connections with MRI cuts acquisition times up to threefold. MRI can be used to estimate the cerebral metabolic rate of oxygen consumptions in the brain in vivo. Improved control over power deposition at 3-Tesla translates into faster body and cardiac imaging. Oxygenation consumption of brain tissue is critical information for the managements of diseases, such as stroke.

Professor Dennis Freeman is engaged in experimental and theoretical studies of how the inner ear processes sound. During the past year, his Micromechanics Group applied a novel optical method to measure sound-induced motions of inner ear structures in vivo. The method is based on optical coherence tomography (OCT), and it allows observation of inner ear structures with a minimum of invasive exposure of the cochlea. The method holds promise to allow direct measurements of cellular motions during cochlear amplification, the process that underlies the exquisite sensitivity and acute frequency selectivity of hearing. These results could have application to the clinical diagnosis and treatment of hearing disorders.

Professor James Fujimoto's group performs research in biomedical optical imaging and OCT. The works spans technology development, fundamental studies, and clinical applications. The group has active collaborations with investigators at Erlangen University in Erlagen, Germany; Harvard Medical School; Ludwig Maximilians University in Munich, Germany; the Medical University of Vienna; Oregon Health and Sciences University in Portland, OR; Tufts University School of Medicine in Boston; and University of Pittsburgh School of Medicine; . The group performs clinical studies with ophthalmology investigators at the New England Eye Center in Boston, Oregon Health and Sciences University, and University of Pittsburgh Medical Center in Pittsburgh, PAgastroenterology and endoscopic imaging at the Harvard Medical School and Boston VA Healthcare System; and pathology at the Harvard Medical School and Beth Israel Deaconess Medical Center in Boston. Professor Fujimoto's group and collaborators were responsible for the invention of OCT in the early 1990s as well as its commercialization by Carl Zeiss and its initial applications in ophthalmology. OCT has become a clinical standard and is the most commonly used imaging procedure in ophthalmology. Working in collaboration with Thorlabs of Newton, NJ, and Praevium Research in Santa Barbara, CA, Fujimoto's group has developed OCT methods using vertical cavity surface emitting lasers (VCSELs). VCSEL frequency swept laser technology for OCT enables dramatic improvements in imaging speed, imaging range and system configurability. The group has recently demonstrated ophthalmic retinal imaging at imaging speeds exceeding 500,000 axial scans per second, a factor of 10 to 20 times faster than current commercial ophthalmic instruments. These high imaging rates enable the acquisition of volumetric 3D data sets that have comprehensive information on retinal pathologies. The researchers believe that these studies will help set the direction for the next generation of OCT technology in ophthalmology.

Working in collaboration with professorHiroshi Mashimo at Harvard Medical School and the Boston VA Healthcare System, the group published a study in clinical endoscopy that used OCT to assess the response to ablative treatments of the esophagus for pre-cancerous pathology (Barrett's esophagus and dysplasia). OCT was demonstrated to identify residual sites of possible pre-cancerous pathology (buried glands) after treatment. This topic is a significant clinical interest because it may mean that patients treated remain at elevated cancer risk and was highlighted in the journal Gastrointestinal Endoscopy and at the Digestive Disease Week Conference (May 2012, San Diego, CA).

The primary focus of professor Martha Gray's research during the last year has been on developing, implementing, and documenting training approaches that promote and accelerate translational biomedical research with potential for high impact. With a cohort of 10 fellows who began July 1, 2011, over the course of one year, the Gray group developed a portfolio of six translational projects in biomedical imaging. Each of these projects addresses a major unmet medical need and has a high potential for impact. The project teams have demonstrated technical proof of concept and are now working to demonstrate clinical validity. It is too soon to say whether all will ultimately be successful; however, the faculty involved agree that the progress made over the past year exceeds the kind of progress typically made by post-doctoral associates in the same time frame. These results have the potential to influence training approaches at MIT and elsewhere.

Professor Jongyoon Han's group has been focusing on developing various engineering applications of ion concentration polarization (ICP). ICP is a transport phenomenon that involves strong, dynamic changes in ion concentration and fluid flow caused by ion-selective membrane. The researchers have been applying this to biosensing, water purification, and even neuroscience. In November 2011, they published a seminal paper in Nature Materials (Song Y-A, et al, Nature Materials, 2011; 10:980–986), that showed that ion-selective-membrane electrodes can be used for significantly lowering nerve activation threshold, and for inhibiting unwanted nerve signals. They tested this concept in an ex-vivo model of frog sciatic nerve. When extracellular calcium concentration was locally and temporarily modulated using the device, they were able to achieve much lower current threshold for electrical activation of nerve. This result has a broad implication in neuroscience and technology, especially in the area of nerve prosthetics engineering. The researchers believe this technology could be used to increase the energy efficiency of existing neural prosthetics, as well as minimizing side effects of current functional electrical stimulation systems such as pain and parasitic non-specific nerve activation.

The Computational Physiology and Clinical Inference Group, co-directed by professor George Verghese and principal research scientist Thomas Heldt, is focused on "bedside informatics," using physiologically based dynamic models to make sense–on seconds, minutes, and hours timescales–of multivariate monitoring data collected at bedside in critical care, emergency room, operating room, or general wards, and even extending into ambulatory situations. Several clinical collaborators participate in their work. During the past year, researchers extended and published work on noninvasive estimation of intracranial pressure (ICP), and also published the results of research on modeling ventilatory instability. In addition, they made good strides on projects related to classification of disease state based on capnography (recordings of exhaled

CO_2 concentration), and detection of impending decompensation in pediatric patients on the general wards. Over the past several years, the group has been developing a model-based approach to noninvasive, continuous and patient-specific estimation of absolute ICP, and this work came to fruition in April 2012, with publication in Science Translational Medicine (Kashif, FM, et al., Science Transitional Medicine, 4: 129ra44, April 2012) of the details of the method and the validation results. The achieved accuracy, on archived records from comatose patients with traumatic brain injury (TBI), is already comparable to that of some invasive ICP measurement methods in current clinical use. The researchers anticipate further improvements using a new component-based system that they are constructing, and with better controlled data collection as they set up for additional validation studies with a Boston-area hospital. Their work on modeling ventilatory instability appeared in the Journal of Applied Physiology (Nemati, S, et al., Journal of Applied Physiology, 111, 1, 55–67, 01358.2010, July 2011). It reports on a method based on trivariate autoregressive modeling, using ventilation, end-tidal carbon dioxide partial pressure and oxygen partial pressure. The method provides for estimation of the overall “loop gain” of the respiratory control system, and its components, namely chemoreflex gain and plant gain. The results were validated on data from lambs.

The results of the group’s work so far confirm their research direction. Ample evidence links increased ICP to poor patient outcome. Yet the determination of increased ICP is fundamentally limited because of the invasiveness of the measurement modality. Consequently, the overwhelming majority of TBI patients–those with mild and moderate TBI from falls, sports or car accidents–currently do not receive the benefit of ICP determination. Likewise, patients with altered mental status or cognitive/psychological disorders, hydrocephalus, implanted shunts, brain tumors, and neuro-ophthalmologic lesions largely go unmonitored. A robust, noninvasive and patient-specific method for determining ICP at clinically acceptable accuracy will have tremendous impact on the diagnosis and tracking of neurological conditions. Apart from expansion of ICP monitoring to a much larger patient pool in whom ICP monitoring might be indicated, such a method will allow triage at the point of patient contact (such as football field, ambulance, and doctor’s office) and in-time and goal-oriented application of therapy, all of which are currently critically lacking in the majority of brain-injured patients.

Professor Timothy Lu’s Synthetic Biology Group seeks to construct and re-encode biological systems from the ground up. As a complement to systems biology, which explores how biology operates from the top down, synthetic biology can provide scientists with the ability to learn about biological systems by building them. This approach can reveal details relevant to the design and behavior of biological networks that cannot be solely detected from the top down. Significant progress has been made in DNA synthesis and assembly, resulting in the ability to completely synthesize entire genomes. However, the complexity of synthetic gene circuits has not scaled concomitantly. This limitation is due to bottlenecks in the design process for synthetic biological systems, which include a lack of well-characterized and extensible parts, poor predictive models, and long lag times in the design-build-test cycle. To address these limitations, the group’s researchers are developing extensible platforms for engineering transcription factors and memory devices with tunable functionalities.

They have created libraries of synthetic transcription factors through the modular assembly of DNA-binding domains, protein-protein interaction domains, and activation/repression domains. A significant result of this work is creation of a library of 19 new synthetic transcription factors in Saccharomyces cerevisiae using a scalable platform. Professor Lu's group explicitly showed that synthetic transcription factors can be orthogonal with respect to one another. Using these synthetic transcription factors, the researchers were able to construct cooperative multi-signal integration circuits. These synthetic transcription factors will be applicable for a variety of applications in biotechnology, synthetic biology, and basic biological studies. The publication of this library demonstrates that synthetic biological devices can be used to implement complex behaviors in eukaryotes.

Professor Rahul Sarpeshkar has worked on constructing a glucose fuel cell for implantable brain-machine interfaces. This cell could enable the powering of ultra-low-power medical implants with glucose in the cerebrospinal fluid in the brain (or in the blood and interstitial fluids in the future). The fuel cell, described in PLoS ONE (Rapoport BI, et al., PLoS One, 7, 6, 338436, June 2012), worked with a platinum catalyst in a completely enzyme-free fashion. Thus, it has the potential for long-term implantation in the body without enzyme degradation that has plagued such fuel cells. Prior research on ultra-low-power medical implants from the Sarpeshkar laboratory potentially can enable a complete paralysis implant to be powered off such a device. All kinds of medical implants such as those for blindness, epilepsy, cardiac disorders, and deafness could benefit from such a glucose fuel cell as well as treatments for diabetes. A good indication of the widespread applicability of this work is the interest that it garnered: The paper in PLoS ONE had more than 8,000 views in less than a month, over 150 news articles have been written on it, and Professor Sarpeshkar was interviewed by the BBC concerning these developments.

In Stefanie Shattuck-Hufnagel's Speech Communication Group, major research issues addressed this year include models of the processing of speech prosody (intonation and timing); phonological and phonetic development in children; rhythm processing in speakers with aphasia; models of speech timing; development of novel methods for measuring prosodic abilities in children; and models of speech error production. In work with associate professor Rupal Patel of Northeastern University in Boston, supported by the National Institutes of Health. Professor Shattuck-Hufnagel's group has developed an interactive graphics tool that allows children (both typically developing and disabled consequent to either congenital or acquired cerebral palsy) to indicate their knowledge of prosodic phonology by manipulating a visual display to control both pitch and duration of synthesized utterances. This tool, called the Prosodic Marionette, allows the child to demonstrate his or her understanding of prosodic accentuation and phrasing, even though their vocal tract motor control problems prevent them from producing targeted prosody. This enables testing of the hypothesis that the child's developing phonological knowledge of the contrastive prosodic categories of the adult language is hindered by his or her inability to produce target prosody motorically, as has been demonstrated for contrastive segmental sound categories. In addition, the Prosodic Marionette method enables investigators and clinicians to probe the development of prosodic knowledge in children with poor motor control, as in cerebral palsy, allowing clinical intervention to focus on improving linguistic knowledge versus articulatory implementation, as appropriate. Their findings and arguments regarding speech production planning have implications for human models of speech processing, automatic speech processing algorithms, and both clinical and pedagogical methods.

The RLE Sensory Communication Group led by Professor Lou Braida investigates topics in three broad areas: hearing aids, the tactile communication of speech, and auditory perception and cognition. The long-term goal of the hearing aid research is to develop improved hearing aids for people suffering from sensorineural hearing impairments and cochlear implants for the deaf. Efforts are focused on problems resulting from inadequate knowledge of the effects of various transformations of speech signals on speech reception by impaired listeners, specifically on the fundamental limitations on the improvements in speech reception that can be achieved by processing speech. The long-term goal of the tactile communication research conducted by the group is to develop tactual aids for persons who are profoundly deaf or deaf-blind to serve as a substitute for hearing in the reception of speech and environmental sounds. This research can contribute to improved speech reception and production, language competence, and environmental-sound recognition in such individuals.

The work of senior research scientist Mandayam Srinivasan focuses on the development and evaluation of a desktop virtual environment system with audio and haptic (touch) interfaces to help people who are blind explore and become familiar with unknown places (e.g., a train station or a shopping center) before actually visiting them. The potential application is similar to the way sighted people use MapQuest or Google Maps. The system is also intended to enhance orientation and mobility training for blind people. The audio interface provides 3D spatialized sounds (like standing in the actual space) and the user can feel a scale model of the simulated space through the hand-held stylus of a robotic device (like a miniature white cane). This work is the continuation of a collaborative project, funded by a NEI R21 grant, between the MIT Touch Lab and the Carroll Center for the Blind in Newton, MA, a rehabilitation and training center for blind and visually impaired persons. The Srinivasan group is beginning pilot experiments in connection with the technical development. Improved non-visual methods for exploring virtual environments may provide a better way for blind and visually impaired persons to interact with computers in general. Specifically, the methods the group is developing could have very broad application in areas that involve learning about or communicating spatial information. For example, such areas might include art appreciation, exploring the Internet, or helping students to better understand graphs in a math or science class. Just as interactions through touch-sensitive screens of mobile and tablet devices are popular among sighted users today, in the future, sophisticated 3D haptic interactions with computational devices by all users, irrespective of whether they are sighted or visually impaired, could be ubiquitous. The work the group is doing in this project will help develop the generic principles in the design and implementation of such haptic user interfaces.

Professor Joel Voldman's research is concerned with developing microsystems for manipulating cells for fundamental and applied biology. His group pursues four main research themes: technologies for image-based cell sorting, novel dielectrophoretic cell separators for cell screening, microtechnology for studying stem cell biology, and microsystems for electrically interfacing to the nervous system. His group demonstrated for the first time that microfluidic liquid flow could be used to productively alter soluble signaling in stem cells. Over several years the researchers have developed microfluidic devices that use fluid perfusion to sweep away cell-secreted molecules, reducing cell-to-cell diffusible signaling. Understanding the role of this diffusible signaling is critical for controlling the fate of these cells and thus for their eventual use. In the past year, the team published two studies uncovering the existence of previously unknown diffusible signals in mouse embryonic stem cell (mESC) neural specification (PLoS ONE, 2011) and self-renewal (PNAS, 2012). For example, the researchers found that culture of mESCs in conditions previously thought to support self-renewal was not in fact sufficient when diffusible signaling was downregulated with perfusion. Instead, they found that the cells required a signal that acted through the extracellular matrix, which was removed under perfusion.

The microfluidic tools Professor Voldman's team developed to generate these results can applied to a range of cell systems. For example, diffusible signaling is really important in cancer biology. In addition, the researchers are following up on these results by finding the identity of the molecules involved in the process they uncovered, which will result in improved control of stem cells.

Following 23 years of work in the development of a retinal implant for the blind, professor John Wyatt's research group has decided to push hard toward a commercially viable device. This may well require that the group first develop it in another country, since the costs of obtaining Food and Drug Administration approval in the US are so high. The researchers have focused on the development of a high-density, miniature implantable wireless neurostimulator capable of driving over 256 separate microelectrodes. In academic year 2012, professor Wyatt's group has developed hermetic co-fired ceramic feedthroughs and the means to attach these to the laser-welded titanium packages they use. In addition, the researchers have micro-fabricated arrays with more than 256 microelectrodes and tested them for connectivity, and they have designed, had fabricated, and tested two versions of the microchip which will control the implant. Since this is a very ambitious development area, rather than a blue-sky research enterprise, Professor Wyatt says that the most interesting results are the successful ways the researchers have found to accomplish various design and fabrication tasks. Once they have succeeded in successfully implanting their device in a half-dozen patients, the consequences will be significant for the millions of people world-wide who have lost vision due to outer-retinal degenerations such as retinitis pigmentosa and macular degeneration. Furthermore, the technology they are developing will make it possible to implant stimulators that drive hundreds of microelectrodes rather than the tiny numbers (certainly under a dozen) that implantable devices now use, which will allow a great improvement in the electronic stimulation and control of the body when medically required.

Nanoscale Science And Engineering

This research theme covers work in fabricating surface structures at nanoscales, nanomagnetics and microphotonics, periodic structures, superconductive materials, and carbon nanotubes.

Professor Karl Berggren studies the self-assembly of block copolymers and developing methods for templating self-assembly in order to form well-organized structures useful in nanoscale manufacturing. Researchers in his group showed that by using a post array coated with a polymer brush attractive to the majority block, they can create a rich variety of structures in which the orientation of each layer of cylindrical microdomains is independently controlled. Moreover, they demonstrated aperiodic structures in which each layer of cylinders can be routed independently to form bends and junctions. This novel method provides excellent registration between the layers in a single self-assembly step. Independently and simultaneously controlling two layers of block copolymer and fabricating a rich variety of complicated 3D structures are key novel features of their work, and there is no comparable report in the literature showing such a level of control over multilayer microdomains. The results of these experiments have several potential applications such as fabrication of vias for the semiconductor industry, bit-patterned media, water purification, membranes and organic photovoltaics.

Fibers are among the earliest forms of human expression, yet surprisingly have remained unchanged from ancient to modern times. Can fibers become highly functional devices? Can they see, hear, sense and communicate? Professor Yoel Fink's research focuses on extending the frontiers of fiber materials from optical transmission to encompass electronic, optoelectronic, and even acoustic properties. In recent years his group has pioneered a new approach to fibers that are made of a multiplicity of disparate materials arranged in elaborate geometries with features down to 10 nanometers. Two complementary strategies towards realizing sophisticated functions are utilized: on the single-fiber level, the integration of a multiplicity of functional components into one fiber, and on the multiple-fiber level, the assembly of large-scale fiber arrays and fabrics. These multimaterial fibers offer unprecedented control over material properties and function on length scales spanning the nanometer to kilometer range. The research highlights of the past year involve a new fiber laser with a cylindrical wavefront and purely radial emission (Stolyarov, AM, et al., Nature Photonics, 6, 4, 229-233, April 2012) with an intensity profile that can be controlled as a function of angle. Another significant development was the discovery of a new route to nanoparticle formation utilizing a fluid instability occurring in fibers that allows for an unprecedented control over particle composition, architecture and scale.

Professor Jing Kong's research focuses on optimization of graphene synthesis and fabrication steps for high-performance transistor devices; synthesis of hybrid graphene-hexagonal boron nitride (hBN) structures; using graphene as transparent electrodes for organic photovoltaic (OPV) solar cells; synthesis of AB-stacked bilayer graphene; and fabrication of aerogel materials from 1D nanowires and 2D nanosheets. Her group successfully synthesized graphene and hBN hybrid structures and clearly confirmed that hBN is a superior substrate for graphene devices, and hBN passivated graphene edge shows less defect-related Raman signal than open graphene edge. Surprisingly, the stacking of graphene and hBN shows very interesting AA-like stacking, which is different from theoretical prediction and requires further investigation. The researchers also have gained further understanding about using graphene as transparent electrode for OPV devices. By engineering the interface, they were able to obtain high yield fabrication of OPV devices with graphene electrode, and the device performances are comparable to those with indium tin oxide (ITO) devices. With this interface engineering, professor Kong's group was able to use graphene for both anode and cathode in OPV devices, and to use graphene electrode for organic-inorganic hybrid (nanowire-polymer and nanowire-quantum dot) solar cell devices. Performances of these devices are either comparable to, or in some cases even better than, devices with ITO electrodes. The researchers are filing two patents regarding the work in this area.

Photonic Materials Devices And Systems

This research theme includes significant efforts in integrated photonic devices, modules and systems for applications in communications and sensing, femtosecond optics, laser technologies, photonic bandgap fibers and devices, materials fabrication, laser medicine and medical imaging, and millimeter-wave and terahertz devices.

Professor Vladimir Bulović and colleagues determined the limits of nanostructured photovoltaic (nano-PV) technologies, including molecular organic, polymeric, dye-sensitized, and colloidal quantum dot-based solar cells. They considered the specific challenges associated with improving the power conversion efficiency of each technology and analyzing benefits of several approaches for reduced thermal losses beyond the single bandgap limit. They also quantified critical considerations related to the solar module lifetime and cost that are unique to nano-PV architectures. While there may be substantial niche markets for low-cost and low-efficiency PVs (i.e., point of source PV utilization), the scaling required to have a significant impact on energy markets will most likely be achieved through PV systems for grid power generation. Their analysis suggests that a practical single-junction laboratory power conversion efficiency limit of 17% is achievable, with 24% reachable for a practical two-PV-cell tandem. When combined with operating lifetimes of 10 to 15 years, such performance could position nano-PV cells as a transformational technology for solar energy markets.

Professor Peter Hagelstein works on problems in cold fusion. The goal of his research in general is to try to understand the anomalies from a fundamental physics perspective. His research is primarily theoretical, but he interacts with many experimental teams, as well as other theorists. The biggest result has been a proposal for a new relativistic coupling mechanism between lattice vibrations and internal nuclear degrees of freedom. The associated problem is that his group has developed a number of idealized models that seem to capture the essential features of excess heat production in the experiments, but when it comes down to calculating rates from the model, the numbers have always fallen short compared to experiment. This seemed to indicate a lack of understanding as to how the coupling works at the most fundamental level. The identification of this new coupling mechanism changes the picture fundamentally.

Professor Qing Hu studies terahertz (THz) quantum cascade lasers and electronics; sensing and real-time THz imaging using quantum cascade lasers and focal-plane cameras; and high-power mid-infrared quantum-cascade lasers with high wall-plug efficiency. His group has achieved many world records in terms of performance of THz quantum cascade lasers including but not limited to highest operating temperature in the pulsed mode (~200 K without field and 225 K with magnetic field), highest operating temperature in the CW mode (117 K), highest power levels of ~250mW, and the longest wavelength to date 190 mm (corresponding to 1.6 THz). The researchers have performed real-time THz imaging at a video rate of ~20 frames/second. They have developed a novel tuning mechanism that is qualitatively different from all the other tunable lasers, and have achieved continuous tuning over a broad frequency range (~330 GHz). These are experiments with the potential to lead to improvements in sensing, imaging, and high bandwidth communications.

The overall focus of professor Erich Ippen's research is ultrafast optics and its applications to science and technology. His group has continued development of compact optical fiber and waveguide lasers for use in optical clocks and signal processing. Femtosecond studies of the materials and components involved are also central to its research. Optical combs centered at 1.5mm are pursued for a variety of applications including communications, laser radar, precision timing, and spectroscopy. Professor Ippen's group has been at the forefront of developing higher (GHz) repetition-rate fiber lasers. This past year the researchers demonstrated the first fully referenced optical comb at 1.5mm with comb spacing greater than 1GHz. With professor Michael Watts's group, they demonstrated and characterized efficient, and potentially steerable, emission of light from silicon photonic waveguides via metallic nanoantenna arrays. Such arrays are potentially much more compact, efficient, and functional that conventional grating couplers. In addition, Professor Ippen's group made the first measurements of the all-optical switching potential of titania waveguide devices, of interest for silicon-compatible 1.5mm microphotonics because of its immunity to two-photon absorption in that wavelength range. Efficient spectral broadening and Raman shifting were observed.

The work on optical combs is synergistic with research in the Center for Ultracold Atoms and is being considered for use in high-resolution laser radar (LIDAR) work at Lincoln Laboratory. Femtosecond fiber and waveguide laser work (in collaboration with professor Franz Kaertner) is motivated also by signal processing demands of LIDAR and radar applications and by the timing precision required by free electron laser facilities. The group's studies and demonstrations (in collaboration with Kaertner) of silicon nanophotonic circuits are of general importance to advances in on-chip photonic communication and control.

Professors John Joannopoulos and Marin Soljacic work together as a team in the area of nanophotonics. Lately, they have been focused primarily on using nanophotonics for tailoring thermal radiation properties and for tailoring spontaneous emission rates (both via modification of photonics density of states). Many of graphene's unique electronic properties emerge from its Dirac-like electronic energy spectrum. Similarly, it is expected that a nanophotonic system featuring Dirac dispersion (two conical bands touching at a single point, the so-called Dirac point) will open a path to a number of important research avenues. To date, however, all proposed realizations of a photonic analog of graphene lack fully omnidirectional out-of-plane light confinement, which has prevented the creation of truly realistic implementations of this class of systems able to mimic the two-dimensional transport properties of graphene. In a recent published article, they report on a novel route to achieve all dielectric three-dimensional photonic materials featuring Dirac-like dispersion in a quasi-two-dimensional system. They discuss how this finding could enable a dramatic enhancement of the spontaneous emission coupling efficiency (the b-factor) over large areas, defying the common wisdom that the b-factor degrades rapidly as the size of the system increases. This finding is published in Proceedings of the National Academy of Sciences (Bravo-Abad, J., et al, Proceedings of the National Academy of Sciences, vol. 109, 25, 9761-9765, 1207335109 June 2012). These results might enable general new classes of large-area ultralow-threshold lasers, single-photon sources, quantum information processing devices, and energy harvesting systems, synergistic with the research of Michael Watts.

In the last year, professor Steven Johnson's research has primarily focused on problems in nanophotonics (electromagnetic phenomena in wavelength-scale media), but he has also worked on nanofluidic and micromechanical phenomena. There are two important results from this period. The first is a proof of general scaling limitations of electromagnetic "cloaking". The group showed that the problem of making an object invisible (a topic that has attracted great recent interest) becomes intrinsically harder as the size of the object increases. The second is a demonstration of the first practical techniques to simulate near-field radiative heat transfer in microstructured geometries with applications in thermophotovoltaics and thermal lithography.

The focus of Professor Franz Kaertner's work is optical parametric chirped pulse amplification to generate high energy carrier-envelope phase controlled pulses for extreme light matter interaction; attosecond science: ultrafast extreme ultraviolet lithography (EUV) pulsed sources and sources for EUV lithography; photonic analog to digital conversion with silicon photonics and low-noise femtosecond lasers; and femtosecond timing distribution in X-ray free electron lasers. Major results can be described as follows. A novel method of producing intense short wavelength radiation from relativistic electrons has been described and recently appeared in Physical Review Letters (Graves, WS, et al, Physical Review Letters, Vol. 108, 26, 263904, June 2012). This research has been carried out within the DARPA CUBIX program between MIT, Lincoln Lab, and Northern Illinois University. The electrons are periodically bunched at the wavelength of interest beginning with an array of beamlets emitted from a nanoengineered field emission array. Periodic bunching at short wavelength is shown to be possible, and the partially coherent x-ray properties produced by inverse Compton scattering from an intense laser are estimated. The proposed method increases the efficiency of x-ray production by several orders of magnitude, potentially enabling compact x-ray sources to produce brilliance and flux similar to major synchrotron facilities. Work towards realization is in progress.

An additional accomplishment is the demonstration of ultralow timing jitter in femtosecond lasers by measuring the high frequency timing jitter of 10-femtosecond titanium:sapphire lasers, currently limited by pump power noise to be only 13 attoseconds using optical techniques. The quantum limit in the high frequency range is in the zepto-second range. This shows the potential of femtosecond lasers for sampling of even MIDIR signals and photonic analog to digital convertors in general, as well as large scale timing distribution. It also predicts that carefully built few-cycle titanium:sapphire lasers may produce the world's lowest phase noise RF-signals, eventually surpassing cryogenically cooled sapphire oscillators. This work was published in Nature Photonics (Benedick, AJ, et al, Nature Photonics, Vol. 6, 2, 97-100, Feb. 2012). Future applications are expected. The novel coherent x-ray generation mechanism described may be used to construct efficient EUV sources for EUV lithography, which is currently lacking a proper source, the major obstacle in use of EUV lithography and a roadblock to the semiconductor technology roadmap. It may also deliver high enough x-ray flux for phase contrast imaging, a novel imaging modality that is more sensitive for x-ray imaging of bodies than the usual absorption image, which together with the source properties puts less x-ray dose to the patient and provides higher resolution, especially in soft tissues. Ultralow phase noise oscillators are necessary for modern navigation and sensing systems as well as advanced clocks. The demonstrated ultralow jitter levels from mode-locked lasers guide the construction of such devices.

Professor Leslie Kolodziejski and principal research scientist Gale Petrich are focused on the fabrication of optoelectronic devices in II-V compound semiconductors. Active areas of research include the development of optical sources with emission wavelengths greater than 1.55 microns, the development of saturable Bragg reflectors for ultra-short pulse lasers, and the development of ultra-broadband optical modulator centered at a wavelength of 810 nm. The most significant results were the observation of spontaneous emission at 1.9 from an indium-phosphide-based device that utilizes ring resonator(s) coupled to a waveguide, and the aluminum-arsenide (AlAs) oxidation behavior of inverted mesa, broadband saturable Bragg reflectors.

As for future applications, the development of the ultra-broadband modulator that is centered at a wavelength of 810 nm may lead to novel communication schemes and formats suitable for short-range plastic optical fiber applications as well as laser ranging applications. The development of tunable long wavelength optical sources utilizing ring resonators provides the excitation energy that is required in chemical sensing applications. The development of saturable Bragg reflectors that contain AlAs that is thermally oxidized to form AlxOy allows fiber or solid-state lasers to emit ultra-short pulses or allows the center wavelength of the laser to be tuned while emitting pulses that are slightly broader in time. The use of an inverted mesa configuration greatly simplifies the alignment of the saturable Bragg reflectors within the laser cavity.

Professor Michael Watts has been focused on 3D integration of silicon photonics with CMOS electronics for a variety of applications including ultralow power wavelength division multiplexed (WDM) optical communications, optical phased arrays, optical beam-steering, low-phase-noise optical-microwave oscillators and microwave signal generation. The researchers have demonstrated the largest optical phased array ever produced, at 4,096 elements, projecting the MIT logo in the far-field. Additionally, they have demonstrated the ability to steer such a nanophotonic phased array using thermo-optic phase shifters. Finally, they have taped out perhaps the most intricate 3D

CMOS-photonic chips ever produced. The results from the phased arrays, low power communication links, and microwave-photonic circuits are likely to impact accident avoidance technologies in automobiles with chip-scale laser detection and ranging. The low power communication links are likely to impact the implementation of low power, high-performance data center, and their work on optical-microwave oscillators is likely to impact wireless communications and global positioning systems.

Quantum Computation and Communication

This area of research features efforts in quantum information processing and transmission, with extensive new initiatives in quantum computation, superconducting circuits, and understanding and exploiting quantum teleportation.

The Quantum Engineering Group investigates the dynamics and control of quantum systems with the goal of building computational and measurement devices that exceed the power of their classical counterparts. To accomplish these objectives, professor Paola Cappellaro's first approach is to study large quantum systems comprising many nuclear spins via nuclear magnetic resonance in order to explore coherence properties, control, and noise reduction techniques. In the past year, the group has investigated the spin systems in crystals of fluorapatite. This system is of particular interest since it presents a quasi-one-dimensional geometry that is amenable to study of quantum information transport and quantum simulation. The researchers theoretically and experimentally studied the transport properties of spin chains in a thermal state. This regime has often been neglected in the literature, where pure-state chains have usually been considered, but it is more often encountered experimentally. In addition, they are currently exploring, via a collaboration supported by MIT International Science and Technology Initiatives (MISTI), novel materials consisting of apatite crystals with a large amount of spin defects that could be used for spin initialization and transport. This work is also supported by the MISTI Hayashi Seed Fund, and a National Science Foundation Division of Materials Research award.

In a different, bottom-up, approach, the researchers are studying a diamond defect, the nitrogen-vacancy (NV) color center. NV centers could be used as building blocks for quantum computation and as sensors for magnetic fields and rotations (in magnetometers and gyroscopes). This work is supported by the Air Force Office of Scientific Research (AFOSR) Young Investigator Program and the National Science Foundation Center for Ultracold Atoms. The focus of the past year has been on studying novel strategies for improved sensitivities to a magnetic field using a single NV center and exploiting adaptive methods and continuous dynamical decoupling. This work is supported by National Institute of Standards and Technology (NIST), DARPA Quantum-Assisted Sensing and Readout, and Army Research Office Multidisciplinary University Research Initiative Qubit Enabled Imaging, Sensing and Metrology awards.

Professor Cappellaro's group obtained the first experimental demonstration of quantum information transport in a mixed spin system. While the fidelity of transport was reduced due to initialization and readout errors, the novel spin system that the group will use in the future will correct for these errors. In addition, the researchers explored novel strategies to achieve perfect quantum information transport in arbitrary spin network, even those naturally occurring. This relaxes tremendously the requirement for spin engineering and thus paves the way to an experimental implementation.

The group also made further significant advances in quantum metrology. This work is supported by a Multidisciplinary University Research Initiative grant by AFOSR, involving other RLE principal investigators as well as researchers at Harvard University, the University of Connecticut at Storrs, and NIST. The researchers achieved major results including a novel adaptive scheme, robust against low fidelity readout, that can achieve the quantum metrology limit; improved magnetometry schemes for both DC and AC fields, exploiting the flexibility given by continuous dynamical decoupling schemes; and a novel concept for a spin-based quantum gyroscope that promises to achieve long stability with sensitivity comparable to those of MEMS devices.

These novel quantum sensors can have wide applications, from materials science to bio-imaging, as well as for inertial navigation systems.

Professor Isaac Chuang's group has researched quantum information theory and experiment, developing new quantum algorithms and working towards implementation of large-scale, reliable quantum computers based on microfabricated trapped ion systems. Results included a demonstration of a trapped ion system microfabricated on top of an ultra-high-reflectivity optical mirror. This device will allow integration of trapped ion qubits with "flying" optical qubits. Trapped ions provide superb force and field sensing capabilities, due to their use of quantum properties. These sensing capabilities may find application in precision metrology and perhaps also in mass spectroscopy and chemistry.

Professor Seth Lloyd's research is on the interplay between information and energy in physical systems, concentrating on the role of quantum coherence and decoherence. He studies quantum computation, quantum communication, and nanoscale energy transport. During this time period, Professor Lloyd and his colleagues had interesting results. With associate professors Vittorio Giovannetti of the Scuola Normale Superiore in Pisa, Italy, and Lorenzo Maccone of the University of Pavia in Pavia, Italy, professor Lloyd was able to prove the Heisenberg bound for measurement of phase and time. This bound had resisted proof for four decades. With research scientist Masoud Mohseni, he constructed a broadly applicable theory for optimizing quantum transport. They used the theory to characterize the optimal conditions for excitonic transport in photosynthetic systems. With a variety of collaborators, professor Lloyd continued work on optimal quantum channels, identifying both optimal coding and decoding strategies for bosonic channels. Finally, he derived a fundamental bound to the accuracy of measuring spacetime geometry and applied this bound to give a novel derivation of Einstein's equations.

The work on the Heisenberg bound and on channel capacities have potentially strong practical application to optimizing the capacity of conventional communication channels, including fiber-optic and free-space communication, and the work on quantum transport has broad application to optimizing energy and charge transport in nanoscale systems, including the construction of novel photovoltaics and nanoscale energy conversion systems.

Professors Jeffrey Shapiro and Franco N.C. Wong have been working on theory and experiment related to reaching ultimate quantum limits in communication and imaging at optical frequencies, where quantum noise is often dominant and conventional techniques are known not to reach ultimate performance limits, e.g., channel capacity of optical communication at high photon and spectral efficiency through a free-space channel. They have obtained preliminary experimental proof-of-principle for the use of quantum illumination—an entanglement-based technique—to permit secure optical communication in the presence of eavesdropping even though the eavesdropper receives more optical power than does the intended receiver. Unlike quantum key distribution systems, their quantum illumination protocol can transmit data and perform key distribution. Their initial quantumillumination secure communication experiment was performed at kHz data rates, dictated by the equipment available to them. Its high data-rate implementation and complete security analysis is one of two major tasks on a DARPA proposal that they have submitted, with MIT as the lead of a team that includes researchers at Louisiana State University in Baton Rouge, Raytheon BBN Technologies, UCLA, and the University of Waterloo.

Personnel

Yoel Fink, professor of materials science and an MIT MacVicar Fellow, succeeded Jeffrey Shapiro as director of the Research Laboratory of Electronics on September 1, 2011. Fink also leads Fibers@mit in RLE and has been active in the Institute for Soldier Nanotechnologies and the Center for Materials Science and Engineering at MIT. His research has led to an entirely new class of fiber materials that function as electronic, optical, or acoustic devices yet are produced using low-cost, scalable fiber manufacturing approaches. He is a co-founder of a medical device company, OmniGuide of Cambridge, MA, where he served as chief executive during a leave of absence from MIT.

RLE welcomed MIT professors Polina Anikeeva, Mildred Dresselhaus and Jeffrey Grossman as new members.

Yoel Fink was promoted to full professor of materials science and engineering

David J. Perreault was promoted to full professor of electrical engineering.

Marin Soljacic was promoted to full professor of physics.

Vladan Vuletic was promoted to full professor of physics.

Elfar Adalsteinsson was granted tenure.

Steven G. Johnson was granted tenure.

Jing Kong was granted tenure.

Collin M. Stultz was granted tenure.

Michael Watts was promoted to associate professor of electrical engineering.

Joseph Foley (financial assistant), Christine Gilman (senior administrative assistant), Erik Kloppenburg (administrative assistant) and Rita Patel (fiscal officer) joined RLE headquarters.

Cherry Mui was promoted to assistant fiscal officer.

Nan Lin (senior fiscal officer), Dave Foss (assistant director of IT Services), and Krista Van Guilder (manager of media and design), were honored with a 2012 MIT Infinite Mile Award.

RLE lost a beloved member of the community, professor David Staelin, who passed away in November 2011. The David H. Staelin Fund was subsequently established to support an endeavor that his family and closest colleagues knew would be of utmost importance to him: an endowed fellowship in RLE for first year graduate students doing research in RLE.

Faculty Honors and Awards

Vladimir Bulovic received the SEMI Award for North America and the Faculty Research Innovation Fellowship.

Paola Cappellaro was selected an Air Force Office of Science Research Young Investigator Award recipient.

President Barack Obama named Mildred Dresselhaus as winner of the Enrico Fermi Award. Professor Dresselhaus was also among seven pioneering scientists worldwide named as recipients of the Kavli Prizes. Norway’s King Harald will present the Kavli Prize in Astrophysics, Nanoscience and Neuroscience to the seven laureates at an award ceremony in September 2012 at Oslo Concert Hall.

James Fujimoto received the Carl Zeiss Research Award in November 2011. “The Carl Zeiss Research Award has been presented every two years since 1990 in honor of outstanding achievements in international optical research. It is one of the most prestigious prizes in the field of optics.”

Timothy Lu was awarded this year’s Henry L. and Grace Doherty Professorship in Ocean Utilization. He was also the winner of the National Institutes of Health New Innovator Award for “high-throughput nanoscale approaches to studying and inhibiting amyloid toxicity.”

Marin Soljacic’s company WiTricity was selected by MIT Technology Review as one of the 50 Most Innovative Companies in 2012.

George Verghese was named Henry Ellis Warren Professor of Electrical Engineering.

Mehmet F. Yanik won the Pioneer Award for “generating transplantable neurons by in vivo combinatorial screening of transcription regulator RNAs.”

The research team that developed optical coherent tomography received the Champalimaund Foundation Vision Award, one of the largest in science at an amount of 1 million euros. The research team and co-recipients are research associate Eric Swanson (RLE), James Fujimoto (RLE, EECS), Carmen Puliafito (Keck School of Medicine, University of Southern California), Joel Schuman (University of Pittsburgh School of Medicine), and David Huang (Oregon Health and Sciences University, former MD/PhD student, Harvard-MIT Division of Health Sciences and Technology). The award is shared by an additional research team working on another topic in vision research.

Professor Fujimoto serves as co-chair for the Biomedical Optics Symposium (BIOS) at Photonics West (Society of Photo Optical Instrumentation Engineers). The BIOS meeting is the largest conference in the field of biomedical optics with over 30 separate conferences and 1,500 papers.

Student Awards

Doctoral student Yen-Fu Cheng was named the recipient of the 2012 Helen Carr Peake Research Prize.

Doctoral students Faraz Najafi and Keith Winstein were named the recipients of the 2012 Claude E. Shannon Research Assistantships.

Research and Administrative Initiatives and Events

The MIT-Harvard Center for Ultracold Atoms had its National Science Foundation grant renewed for five years at $12.5 million. This is the third phase of an extensive program that has successfully advanced in its research program concerning strongly correlated states of matter in many-body systems and in few-body system (consisting of single or several ions, atoms and photons).

The M+Visión biomedical imaging initiative, a unique collaboration between MIT and Madrid, Spain, begun two years ago, now has three fellowship classes. These are early-career individuals with an MD, PhD, or MBA degree, who have an interest in imaging and translational research. M+Visión held its first biomedical imaging innovation conference in Madrid in May; 350 people from technology fields, university research, and the private sector attended. The meeting presented opportunities for networking and learning for professionals, researchers and practitioners from all over the region.

The Quantum Information Science and Technology Laboratory (QISTL), directed by senior reseach scientist Franco Wong, opened for lab tours. QISTL is a state-of-the art quantum optics laboratory and a key component of MIT's Interdisciplinary Quantum Information Science and Engineering (iQuISE) graduate training program.

RLE celebrated with the Microsystems Technology Laboratory the opening of a new Electron-Beam Lithography Facility.

Yoel Fink implemented the first RLE Board that is chartered with advising the RLE director on the stewardship of the Laboratory and aiding in the strategic planning of RLE's future. Fourteen faculty members and an industrialist serve on the Board:

Professors Marc Baldo, Karl Berggren, Isaac Chuang, Yoel Fink, Erich Ippen, Wolfgang Ketterle, Leslie Kolodziejski, Muriel Medard, David Perreault, Rajeev Ram, Jeffrey Shapiro, Joel Voldman, and Greg Wornell; and Raymond S. Stata '57, chairman and cofounder of Analog Devices, Inc. New financial initiatives include creation of a lab endowment to pay annual interest and to serve as the basis for discretionary spending. Initial efforts have focused on refreshing the RLE governance structure; improving inter- and intra-lab communications; increase financial sustainability; and placing RLE in a position to be an important contributor to MIT-wide initiatives. To facilitate organizational learning through feedback, Professor Fink asked MIT's Institutional Research to design and implement a customer satisfaction survey in which principal investigators were asked about areas of strength and areas for improvement in RLE's administrative services. Survey data is being used to provide some indication of how resource allocation may be prioritized. Approximately 80% of investigators responded. In February 2012 results were shared with the whole community including action plans, e.g., a new RLE-IT ticket-based tracking system.

RLE initiated a funding research effort to help principal investigators to be more effective at fundraising, recognizing that their time available to discover new funding sources is very limited. The ultimate aim is to build organizational capacity around team building, foster interdisciplinary research, and increase visibility to funding trends, moving toward a "proactive lab."

RLE also opened a research café on the 8th floor to facilitate interactions among principal investigators and students.

Affirmative Action and Outreach Activities

The Research Laboratory of Electronics has hosted a number of outreach activities, as highlighted below.

QuISU. Under the sponsorship of the National Science Foundation, several RLE faculty members hosted a group of 13 rising college seniors (three of them women, one Hispanic and two international) for a week-long program on Quantum Information Science for Undergraduates (QuISU) in summer 2011, under the direction of professors Isaac Chuang and Jeffrey Shapiro. Graduate students from the iQuISE program (Interdisciplinary Quantum Information Science and Engineering) got involved as well. To propel recruitment of students from underrepresented groups to MIT, the QuISU program serves as a feeder program to iQuISE.

Lab Tours/Open House. Three iQuISE trainees, Arolyn Conwill, Michael Gutierrez and Kristin Beck, opened up their labs on November 19, 2011, to physics undergraduates from the State University of New York, College at Cortland. The group and professor Brice Smith saw labs in the Vuletic and Chuang groups. The group of about 10 students learned about the promise of quantum computation with molecular ions and using atomic gases for manipulating photon statistics.

CUA Kids Day. The Center for Ultracold Atoms sponsored an afternoon of demonstrations and lab tours for middle school students and 9th graders from the Cambridge and Boston schools on April 27, 2012. Seventy students, teachers, and parents attended and saw a tornado machine, an ion trap, and a nitrogen experiment. Graduate students and postdocs led the demos and the lab tours in three laboratories. This was done in collaboration with the Cambridge Science Festival.

Ultracold Physics with Wisconsin Sixth-graders. Wolfgang Ketterle and graduate student Ivana Dimitrova answered letters from six 6th-grade classes in Wisconsin. Each letter included three questions on cold atoms science, which were discussed by the class.

Visiting Students and Faculty. RLE principal investigators have reached out to students and faculty from universities where the research experience is not comparable to MIT.

Karl Berggren hosted interns from universities without substantial capacity to offer research opportunities in engineering. These included Thomas Rembert in the summer of 2011 as part of the Center for Materials Science and Engineering summer internship program (University of Arkansas) and Prashanta Kharel in the summer of 2011 (University of the South). Amir Travakkoli, National University of Singapore, and José Arrieta, University of Costa Rica were also invited to work in Professor Berggren's lab. These students came under their own individual sponsorship. Finally, Professor Berggren reached out to Winsor School, a private girls' school in Boston, and hosted Wei-Wei Lu in his lab for one month. A visiting faculty member from the University of the South, Randy Peterson, was also invited to work in his lab, working on proximity-effect correction in electron-beam lithographer as a part of Professor Berggren's National Science Foundation program on single-photon detectors.

Professor Timothy Lu, in summer 2011, hired both Adekemi Victoria Adeleye and Gregory Miller, students at Roxbury Community College. Miller stayed on throughout the fall term as well. Adeleye worked with a grad student on engineering biological nanowires and Miller worked with a grad student on synthesizing artificial transcription factors. These were internships coordinated with the REU (Research Experience for Undergraduates) program at MIT.

Yoel Fink
Director
Professor of Materials Science and Engineering
Joint Professor of Electrical Engineering and Computer Science