Research Laboratory of Electronics

The Research Laboratory of Electronics (RLE), founded in 1946, is the Institute's first interdisciplinary research laboratory. RLE grew out of the wartime MIT Radiation Laboratory and was formed to bring together physicists and electrical engineers to work on problems in electromagnetic radiation, circuits, and specialized vacuum tubes. Over the years, RLE's research interests have branched in many directions so that today it is the most intellectually diverse of MIT's interdisciplinary research laboratories. Research within RLE today is conducted by approximately 64 faculty members affiliated with the departments of Biological Engineering, Electrical Engineering and Computer Science, Physics, Mechanical Engineering, Materials Science and Engineering, Mathematics, Nuclear Science and Engineering; the Engineering Systems Division; and the Harvard-MIT Division of Health Sciences and Technology.

During the past year, approximately 300 graduate students and 100 undergraduates from nine MIT departments and divisions pursued research within RLE. The research is supported primarily by Department of Defense (DOD) agencies, the National Institutes of Health (NIH), the National Science Foundation (NSF), the Department of Energy (DOE), and the National Aeronautics and Space Administration (NASA). In addition, numerous projects are funded through industry and private foundations. RLE research is widely varied and now consists of seven major interrelated groupings: circuits, systems, signals, and communications; energy, power, and electromagnetics; multiscale bioengineering and biophysics; nanoscale science and engineering; photonic materials, devices, and systems; physical sciences; and quantum computation and communication. Work in energy, power, and electromagnetics represents a new emphasis within RLE that has been spurred by incorporation of the Laboratory of Electromagnetic and Electronic Systems into RLE and creation of the DOE-sponsored Center for Excitonics. The latter is the fifth virtual center hosted by RLE, the others being the NSF-sponsored MIT-Harvard Center for Ultracold Atoms, the W. M. Keck Foundation Center for Extreme Quantum Information Theory, and the Interdisciplinary Quantum Information Science and Engineering program, which is supported by an NSF Integrative Graduate Education and Research Traineeship grant, and the Madrid-MIT M+Visión Program.

Detailed information about RLE research in 2009-2010 can be found in RLE Progress Report Number 152. The report is available online at http://www.rle.mit.edu/media/media_pr.html. The following is a summary of research highlights from the past year.

Circuits, Systems, Signals, and Communications

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 focusing on 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 focusing on the 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 (IBM, Intel, and Mentor Graphics). Technology transfer is happening via summer internships and visits. Other research centers such as the Politecnico di Torino, 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 (FBARs), based on measurements produced in collaboration with the group of professor Duane Boning at Microsystems Technology Laboratories. In addition, they have recently 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 Pharmaceutical, is already showing a promising application. They plan on intensifying these efforts in the future with the goal of enabling diagnosis of cerebral blood flow issues, in collaboration with Philip S. Hsu MD, a neurologist at Tufts University. The Daniel group has also recently started a new collaboration to develop fast simulation and modeling tools for undesired heat deposition in human tissues during Magnetic Resonance Imaging (MRI) in collaboration with: professor Elfar Adalsteinsson of RLE, professor Lawrence Wald at the Massachusetts General Hospital and Harvard Medical School, and Siemens.

Professor Vivek Goyal's research agenda spans several areas of signal processing and information theory. Work in his group is continuing in a variety of areas, including: MRI; optimal decision making under a variety of constraints, especially those related to human cognitive limitations; and design of information representations for networks that combine data acquisition with computation. The most prominent lines of work provide the first exact analyses for a large class of compressed sensing problems and radically novel methods for using time-resolved sensing in optical imaging. In other work, Professor Goyal and his students have introduced a new, broadly-applicable principle that, because the speed of light is finite, time can provide spatial correspondences that are normally provided through focusing optics. In conventional digital photography, the illumination is omnidirectional and focusing optics creates a one-to-one correspondence between scene points and sensor array points. A short and bright flash could reduce the time needed to collect enough light to have good contrast, but time is not used in any other way. Helmholtz reciprocity enables the fascinating trick of dual photography, whereby spatial correspondences come from scanning scene points one-by-one with narrowly focused illumination. The Goyal group has accomplished something radically different: with only omnidirectional illumination and omnidirectional (unfocused) sensing, they are able to generate spatial resolution computationally. While the contribution is first and foremost conceptual, they have also produced two proof-of-concept implementations that are the first to achieve certain fascinating results.

Professor Jae Lim's Advanced Telecommunications and Signal Processing group is developing new video compression methods for use in reducing the bandwidth required for video communications and the storage required for video recording systems. A particular focus is the development of new transforms for video compression systems, which have the potential for efficient transmission of 3D television signals.

The research of professor Vincent Chan and his students addresses a broad range of topics in the general area of networks and communications, with an emphasis on satellite, wireless, and optical systems. The current focus of their effort is the technology and architecture encountered in modern heterogeneous networks. At present, such networks suffer from low throughput, long delays, and an inability to guarantee critical message delivery, among other problems. Addressing these shortcomings requires architectural constructs that range from physical media to upper-layer network protocols. Last year his group's work provided the primary technical input to the networking section of the national-level report "Creating an Assured Joint DOD and Interagency Interoperable Net-Centric Enterprise," which was presented by the Defense Science Board to the DOD. This year they provided many more detailed inputs to the DOD in terms of architecture constructs and important open areas of research. They were also asked by the Large Scale Networking Coordinating Group of the National Coordinating Office for Networking and Information Technology Research and Development out of the White House Office of Science and Technology Policy, together with the NSF and NASA, to organize and chair a workshop on "Highly Controllable Dynamic Heterogeneous Networking" whose purpose was to bring together leading researchers to discuss the research and development activities needed to enable the end-to-end, scalable, highly controllable, secure heterogeneous networks of the future. Through this workshop and some of their own research results Professor Chan and his students have created a research agenda for future generations of high-speed networks. Among the most important foci are the creations of new protocols together with redesign of the communication hardware to foster much improved network performance.

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 most 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. Together with colleagues (Tsu-Jae King Liu and Elad Alon from University of California, Berkeley and Dejan Markovic from UCLA) they received the 2010 International Solid-State Circuits Jack Raper Award for Outstanding Technology Directions Paper for the world's first NEM relay (switch) chip, with basic VLSI building blocks (adder and multiplier cells, flip-flops, memories, ADC and DAC circuits) built entirely out of relays. This year, his group designed and demonstrated the largest-ever working NEM relay circuit — a 100-relay multiplier block. They have also continued to further increase the level of integration of these NEM relays as well as potential technology transfer, and have engaged with both SEMATECH and Texas Instruments to design NEM relay chips to be fabricated by them with improved scaling and increased functionality. 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, Inc to bring the silicon-photonic platform into 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 been awarded the leadership role in a large four-year Defense Advanced Research Projects Agency program to develop this technology, in partnership with Micron, University of California, Berkeley and University of Colorado, Boulder.

Professor Muriel Médard leads a highly collaborative research group with research links that include the Computer Science and Artificial Intelligence Laboratory, the Microsystems Technology Laboratories, and the Laboratory for Information and Decision Systems at MIT, as well MIT Lincoln Laboratory, the California Institute of Technology, the University of California, Los Angeles, Stanford University, Rutgers University, Alcatel-Lucent, Raytheon BBN Technologies, and BAE. Its central theme is communications, with a special emphasis new practical and theoretical developments, in the area of network coding. Some specific achievements during the past year include: the development of new results in network equivalence theory, which significantly changes the understanding of network information theory; the use of network coding to establish anonymous networks for surveillance avoidance; the use of network coding to provide shared proximity-based peer-to-peer exchanges for simultaneous viewing that allows content protection; and theory establishing fundamental limits of combined computation and communications, using degrees of freedom as a common unit.

Professor David Staelin's Remote Sensing and Estimation Group has been actively engaged in research on passive microwave satellite remote sensing and neural signal processing. Professor Staelin and his students have discovered that rain evaporation is a major factor contributing to discrepancies between annual rain-gauge and passive microwave satellite surveys of global precipitation, and developed new methods to correct for this effect that use both relative humidity profiles and land surface classification. This work should find applications within the operational weather satellite and hydrological communities. In other work this year, the Staelin group has developed further a theory for how cortex might learn new information on sub-second time scales using spike processing, and have shown by theory and time-domain simulations using simple neural threshold-firing models that as much as 0.1 bit of Shannon information might be stored per synapse using this learning mechanism. This mechanism requires a state change prior to recall, such as atrophy of little-used synapses or an increase in firing threshold above that used during learning. This mechanism also appears capable of training multiple neural layers efficiently, including both feed-forward and feedback neural paths. The feedback paths appear likely to improve cortical sensitivity to sensory signals in noise, offer advantages of predictive coding when storing information compactly, permit memory and recall of pattern sequences, and enable associative and content-addressable memory.

Energy, Power, and Electromagnetics

Professor Marc Baldo is the director of the DOE-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 publication of the first report of a solar cell that exploits singlet exciton fission. This is a process that splits one high-energy photon into two lower energy photons. This demonstration promises to improve the efficiency of all solar cell technologies.

Professor Peter Hagelstein has continued his efforts on theoretical models for the excess heat effect in the Fleischmann-Pons experiment. His group has developed an improved model for the receiver part of the donor-receiver model, where they found that if they extended the model to a set of three-level systems, instead of two-level systems, they could make a much better connection with experiment. The Hagelstein group has continued working with several experimental groups, suggesting interpretations of existing experiments, and suggesting new experiments. They have continued in their efforts of documenting the models for publication. A doctoral research project is focused on understanding the chemical potential of PdH, PdD and PdT as functions of loading using DFT calculations. The most interesting result is the development of the three-level generalization of the lossy spin-boson model. The reason this is interesting is it allows the Hagelstein group to interpret an experiment done by Karabut in the 1990s as showing the coupling between lattice vibrations and nuclear excitation in its most basic form. They expect to submit a paper for publication on this shortly. This result also makes clear the origin of small beams of gamma radiation near 90 keV reported by Gozzi and coworkers in the 1990s in connection with excess heat observations. If the model can be confirmed in upcoming experiments, it will provide a route to confirm the reaction mechanism for excess heat production in Fleischmann-Pons experiments. These results have the potential to be widely applicable to many physical systems. New energy systems based on the technology have the potential to solve outstanding problems of energy supply, climate change, and clean water. The lack of interest in the results, and near complete absence of support in the area makes it unlikely that a new technology will be commercialized any time soon.

Professor Jeffrey Lang's research addresses the analysis, design and control of electromechanical systems with an emphasis on high-performance electrical machine systems, micro-scale electromechanical actuators and sensors (MEMS), and distributed electromechanical structures. Some of his group's recent work has been inspired by the canal subsystem of the lateral line sensory organ in fish, which acts as an array of pressure sensors. Interpreting spatial pressure gradients with this organ allows fish to perform a variety of actions from schooling, to tracking prey, to recognizing nearby objects. Moreover, the entire lateral line organ enables some species to form three-dimensional maps of their surroundings. Similarly, by measuring pressure variations on a vehicle surface, an engineered dense pressure-sensor array could enable the identification and location of obstacles during vehicle navigation. The development of such a passive system to detect, classify and locate underwater objects could benefit AUVs and ROVs that navigate cluttered environments and surf zones. More generally, the marine industry could benefit from such a pressure sensing system by having available detailed flow maps derived through the pressure measurements. These maps could facilitate the optimized maneuvering and handling of turbulent flows, as well as the development of morphing procedures to reduce drag and optimize agility. Professor Lang and his students have developed a flexible pressure sensor array with a pressure sensitivity of 10 Pa. Each pressure sensor in the array employs a carbon-doped conducting polymer that changes its resistivity in response to strain. In this case, the strain results from a pressure difference across the pressure sensor. To increase sensitivity, each pressure sensor employs a strain-concentrating diaphragm designed to mechanically amplify the strain resulting from ambient pressure gradients, and concentrate that strain on a small area of the strain-sensitive polymer.

Professor Steven Leeb is interested in energy efficiency. His group's work comprises a broad-ranging look at the way electro-thermal-mechanical systems use energy in buildings, with an eye toward advanced technology demonstrations in fault detection and diagnostics, intelligent lighting, power electronics, waste heat recovery, metering, and control. During the past year, the Leeb group has developed a new system for optimizing the energy generated from solar installations by using switched capacitor filters. This approach decouples the utility impedance from the maximum power point tracking control, improving the stability of grid connected PV arrays. A patent has been filed for on this approach. The Leeb group has also established 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 have received a patent on this technique in April 2011 (US Patent 7,923,936) and have filed for others. Further, they have created a new technique for non-contact sensing of current in circuit breakers, speeding the creation of information flow for a "smart grid." Finally, the Leeb group has developed and demonstrated new techniques for using power-system monitoring for condition-based maintenance. They are deploying these techniques in a refinery in Texas and also a US Coast Guard cutter.

Professor Joel Schindall's research activity is aimed at developing a practical energy storage device that combines the long life and rapid charge-discharge capability of a capacitor with the much higher energy storage capacity of a rechargeable battery. The approach is to increase the energy storage capacity of a double-layer capacitor by replacing the usual activated-carbon electrode coating with an array of vertically-aligned carbon nanotubes. Professor Schindall has successfully fabricated and grown nanotubes on an interdigitated conductive substrate, and has measured capacitances in the millifarads. This is far more than can be achieved with traditional parallel-plate capacitors. He has also identified several methods that may allow him to achieve even higher nanotube densities. This type of ultracapacitor can have application in a wide variety of MEMS devices, ranging from power conversion to burst transmitters. In addition, the same techniques can be used in larger devices to provide high burst power for electric automobiles, to increase the capacity of electric grids by providing local storage for load leveling, and to provide backup power in case of electrical outage.

Professor Markus Zahn's work focuses on electromagnetic fields and media. Application areas of interest are: dielectric physics and high-voltage breakdown in gases, liquids, and solids; electrohydrodynamics and ferrohydrodynamics; and the development of dielectrometry and magnetometry sensors for nondestructive testing. Past research has used COMSOL Multiphysics analysis to solve for the electric field and space-charge distributions in two-dimensional axisymmetric electrode geometries from electric breakdown streamers. During the past year, the Zahn group has been able to extend the modeling to full three-dimensional streamers that more accurately model experimental observations. They have also explained how the presence of small conducting nanoparticles defy conventional wisdom by increasing the electrical breakdown strength of liquid dielectrics, converting captured high-mobility electrons to slow negatively-charged nanoparticles carrying trapped electrons with effective mobility reduction by a factor of 10^5.

Multiscale Bioengineering and Biophysics

Professor Elfar Adalsteinsson and his students continue to focus on developing methods for MRIs in human health and disease. The management of local and global power deposition in human subjects (Specific Absorption Rate, SAR) is a fundamental constraint to the application of parallel transmission (pTx) systems. Even though the pTx and single-channel operation have to meet the same SAR requirements, the complex behavior of the spatial distribution of local SAR for transmission arrays poses problems that are not encountered in conventional single-channel systems and places additional requirements on pTx RF pulse design. The Adalsteinsson group proposed a pTx pulse design method that builds on recent work to capture the spatial distribution of local SAR in numerical tissue models in a compressed parameterization in order to incorporate local SAR constraints within computation times that accommodate pTx pulse design during an *in vivo* MRI scan. Additionally, the algorithm yields a Protocol-specific Ultimate Peak in Local SAR, which is shown to bound the achievable peak local SAR for a given excitation profile fidelity. The performance of the approach was demonstrated using a numerical human head model and a 7T eight-channel transmit array. The method reduced peak local 10g SAR by 14-66% for slice-selective pTx excitations and 2D selective pTx excitations compared to a pTx pulse design constrained only by global SAR. The primary tradeoff incurred for reducing peak local SAR was an expected increase in global SAR, up to 34% for the evaluated examples, which is favorable in cases where local SAR constraints dominate the pulse applications. A second research highlight for the Adalsteinsson group involves venous oxygen saturation (Y_v) in cerebral veins and the cerebral metabolic rate of oxygen ($CMRO_2$), which are important indicators for brain function and disease. Although MRI has been used for global measurements of these parameters, currently there is no established technique to quantify regional Y_v and $CMRO_2$ using noninvasive imaging. His group proposed a technique to quantify $CMRO_2$ from independent MRI estimates of Y_v and cerebral blood flow (CBF). The approach uses standard gradient-echo and arterial spin labeling (ASL) acquisitions to make these measurements. Using MR susceptometry on gradient-echo phase images, Y_v was quantified for candidate vein segments in gray matter that approximate a long cylinder parallel to the main magnetic field. Local CBF for the identified vessel was determined from a corresponding region in the ASL perfusion map. Fick's principle of arteriovenous difference was then used to quantify $CMRO_2$ locally around each vessel. Application of this method in young, healthy subjects provided gray matter averages of 59.6 ± 2.3% for Y_v, 51.7 ± 6.4 ml/100g/min for CBF, and 158 ± 18 μmol/100g/min for $CMRO_2$ (mean ± SD, n=12), which is consistent with values previously reported by PET and MRI. A third key accomplishment for Professor Adalsteinsson and his students involves clinical imaging with structural MRI which routinely relies on multiple acquisitions of the same region of interest under several different contrast preparations. The Adalsteinsson group presented a reconstruction algorithm based on Bayesian compressed sensing to jointly reconstruct a set of images from undersampled *k*-space data with higher fidelity than when the images are reconstructed either individually or jointly by a previously proposed algorithm, M-FOCUSS. The joint inference problem is formulated in a hierarchical Bayesian setting, wherein solving each of the inverse problems corresponds to finding the parameters (here, image gradient coefficients) associated with each of the images. The variance of image gradients across contrasts for a single volumetric spatial position is a single hyperparameter. All of the images from the same anatomical region, but with different contrast properties, contribute to the estimation of the hyperparameters, and once they are found, the k-space data belonging to each image is used independently to infer the image gradients. Thus, commonality of image spatial structure across contrasts is exploited without the problematic assumption of correlation across contrasts. Examples demonstrate improved reconstruction quality (up to a factor of 4 in root-mean-square error) compared to previous compressed-sensing algorithms, and show the benefit of joint inversion under a hierarchical Bayesian model.

The general goal of Dr. Bertrand Delgutte's research agenda is to understand neural mechanisms for listening in everyday environments comprising noise and reverberation. This year, one research focus has been on the neural basis for speech reception in reverberant environments. Dr. Delgutte and his group have examined the effect of reverberation on the coding of speech-like sounds in the auditory midbrain. A key research achievement this year is finding that the neural coding of the amplitude envelope of sounds is degraded by reverberation, but the degradation is not as severe as that present in the acoustic stimulus, suggesting the auditory system may possess neural mechanisms for reverberation compensation. In a majority of neurons, this compensation can be explained by the compressive shape of the nonlinear transformation between the amplitude modulation depth of the acoustic stimulus and the modulation depth of the neural response. However, a substantial minority of neurons shows reverberation compensation beyond that predicted by the modulation input-output function. They hypothesize that this reverberant advantage may result from dynamic modulation in the interaural correlation of the ear input signals introduced by reverberation and the strong sensitivity of binaural neurons to interaural correlation. A second research focus this year has been on developing better animal models of cochlear implants for neurophysiological studies. In another set of studies aimed at improving the neural coding of sounds delivered through cochlear implants, the Delgutte group looked at an apparent discrepancy between perception of and neural responses to pulse-train stimuli. While auditory midbrain neurons in anesthetized animals only respond to the onset of pulse-train stimuli at pulse rates above 100-200 Hz, cochlear implant users hear a continuous percept throughout the stimulus duration, and some can discriminate pitch for pulse rates above 200 Hz. They hypothesize that this discrepancy might arise from the use of anesthesia in the animal experiments. By developing an unanesthetized rabbit model of cochlear implants, the Delgutte group has found that a substantial fraction of midbrain neurons gives sustained, temporally precise responses to pulse trains up to the higher rates tested (1200 Hz). These new results (the first neural recordings from the auditory brainstem in an awake preparation with cochlear implant stimulation) bring perceptual and neurophysiological results in closer agreement. The development of this chronic preparation opens up a whole host of new possibilities to study how the development and plasticity of the auditory system in animal models of deafness is shaped by auditory experience provided through cochlear implants.

Professor Dennis Freeman has made further advances in his investigations of the way the inner ear processes sound. Previously, the Freeman group developed a novel optical method to measure sound-induced motions of inner ear structures. The method is based on Optical Coherence Tomography, 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. During the past year, the Freeman group has applied this new method to measure sound-induced motions *in vivo*. They have measured low-frequency motions in the guinea pig, where the low-frequency portion of the cochlea is more readily accessible than it is in other species. Measuring responses to low frequencies is important to test the notion that cochlear outer hair cells contribute energy on a cycle-to-cycle basis during hearing. They have also measured sound-induced motions at high frequencies in the gerbil. Measuring responses at high frequencies is important to test the notion that cochlear amplification sharpens frequency tuning. Finally, they have begun measurements with mice. Measuring cochlear motions in mice is important because genetic modifications of mice allow targeted manipulations to test specific hypotheses about the mechanisms of hearing loss. These results could have application to the clinical diagnosis and treatment of hearing disorders.

Dr. Mandayam A. Srinivasan is interested in the development and evaluation of a virtual environment (VE) 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) before actually visiting them. The audio interface provides three-dimensional (3D) spatialized sounds (like standing in the VE), and the user is able to 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 a collaborative project with The Carroll Center for the Blind, a rehabilitation and training center for blind and visually-impaired persons. The specific aims of the project are: (1) to continue development of BlindAid, the VE system created under a previous grant; and (2) to conduct experiments on the use of the system. During the last year, Dr. Srinivasan and his students focused on two interrelated development areas. The first is to upgrade the BlindAid system to a full 3D VE. The second is to find a comprehensive source of digital maps that may be read by the system. One of the proposed applications, a kind of MapQuest for the blind, will never be possible without a comprehensive set of maps. The type of virtual tools they are currently developing to enhance non-visual virtual exploration will provide people who are blind a new way to learn about and better understand all kinds of 3D objects and the world.

During the past year, the work in professor Jongyoon Han's Micro/Nanofluidic BioMEMS group has focused largely on three new projects: small-scale desalination system prototyping; neural activation via an ion-selective membrane; and a class of novel microfluidic devices (inertial microfluidic devices). The Han group has continued to work on building a small prototype system for portable desalination technology. They have developed an economical, scalable and manufacturable design of the technology, which opens up the possibility of high-flow-rate water purification and commercial translation. The desalination technology, if properly commercialized, will have significant impact on civilian, humanitarian, and military water-purification applications. In addition, they are submitting a new paper on controlling the nerve excitability using ion-selective membrane electrodes, with animal testing results. The neural stimulation project would have the most significant impact where one needs to suppress unwanted nerve signals, as in a disease like epilepsy. Currently, there is no widely accepted method for suppressing action potentials in nerve fibers, and their technology is already validated in frog sciatic nerve. Finally, the Han group has created a class of novel microfluidic devices (inertial microfluidic devices) to separate cells with a high throughput (~1mL/min or more), in order to purify complex cell mixtures, such as mesenchymal stem cells.

Research in professor George Verghese's Computational Physiology and Clinical Inference Group is centered on the development and use of dynamic models from physiology to integrate and interpret, on a seconds-to-hours timescale, the high-resolution multichannel data collected in clinical settings. The objectives are to improve the quality and timeliness of the information provided to clinical staff, in order to support better diagnosis, monitoring, and therapy. This general approach and theme are instantiated in the context of monitoring cardiovascular, cerebrovascular, respiratory and other subsystems, in both adults and neonates, in settings ranging from critical care to (in the case of adults) ambulatory. Over the past year, the Verghese group's most interesting and important results involve noninvasive estimation of intracranial pressure (ICP), the pressure of the cerebrospinal fluid in the cranium that bathes the neural tissue and cerebral vasculature. This pressure ranges from 5-15 mmHg normally, but can become elevated in a variety of conditions (such as traumatic brain injury, hemorrhagic stroke, brain tumors and hydrocephalus), causing rapid deterioration of cerebral perfusion and significant transient or permanent impairment of the brain, or even death. Current approaches to determining ICP are significantly invasive, involving drilling a hole in the skull and advancing a catheter or pressure sensor either into or through brain tissue. Professor Verghese and his students have shown — in tests on archived data from collaborators at Addenbrooke's Hospital, Cambridge, England — that accuracy comparable with that of many invasive methods can be obtained through model-based estimation using data collected noninvasively or with minimal invasiveness. Specifically, they use time-synchronized recordings of arterial blood pressure (sensed via a radial-artery catheter or finger cuff) and of blood-flow velocity in the middle cerebral artery (obtained via a transcranial Doppler ultrasound measurement), folding these together with the constraints imposed by a simple model of cerebrovascular dynamics. In around 2600 comparisons between the Verghese group's ICP estimates (each computed over a 60-heartbeat data window) and invasively obtained ICP, they have a bias of around 1 mmHg and standard deviation of around 8 mmHg. Given that respiration already induces variations on the order of 4 mmHg in mean ICP over a heartbeat, these performance numbers are very encouraging. Having an accurate noninvasive approach to estimating ICP will fill an urgent need in clinical settings as well as in emergency transport, as there is currently no available method to monitor ICP in patients who fall short of meeting the necessarily stringent criteria for invasive measurement, but whose ICP is nevertheless of significant concern.

Professor Joel Voldman's research interest is the development of microsystems for manipulating cells for fundamental and applied biology. His group's four themes are: (1) technologies for image-based cell sorting; (2) novel dielectrophoretic cell separators for cell screening; (3) microtechnology for studying stem cell biology; and (4) microsystems for electrically interfacing to the nervous system. This year, the Voldman group published a number of papers that were the result of many years of work in the laboratory. In one paper, they developed a cell line that could turn colors when the cell was exposed to various types of stress, like heat, or reactive oxygen species. They used these cell-sensors to investigate the impact of electric fields on cells with unprecedented quantitation and throughput. For a different paper, they developed a way of exposing stem cells to different levels of fluid stress to study the effects of that stress on the stem cells' behavior. Fluid flow is a necessary component of bioprocessing stem cells for therapy, but the effects of that flow had not been systematically elucidated for embryonic stem cells. Professor Voldman's study was the first to do so. Moving forward, the Voldman group is expanding their cell-sensor effort to create a rainbow of cell lines, each that glows a different color in response to a specific stress. This will be useful to people who design technology that manipulates cells, as one could test the effects of that technology on cell physiology in a simple yet comprehensive manner.

Professor John Wyatt's Retinal Implant Project aims to create a wireless electronic implant that will restore some useful level of vision to patients who are blind from either retinitis pigmentosa or severe cases of macular degeneration. In the effort to create a device that the Wyatt group can submit to the FDA for permission to begin human trials, the project has temporarily evolved from a research to a development phase in which all their workers are full-time engineers. This transition is necessary to create a device that is sufficiently safe and reliable for human work, which will lead to a whole new round of more fundamental research that they will pursue. In previous years, the group completed three versions of the implant and implanted them in the eyes of Yucatan minipigs to test for biocompatibility and the ability to function for up to a year in the saline environment of the eye. This past year has been devoted to the development of Generations 4 and 5 of the implant. Generation 4 uses the older chip, but in a tiny hermetic package with at least 200 feedthroughs, to allow separate wires to exit the chip to drive individual pixels. This number of feedthroughs is over an order of magnitude higher than any commercially-available implant can offer, and the development of a tiny package with this number of feedthroughs is a major contribution to the field. Generation 5 will use a more advanced version of the package with a new, safe chip that Professor Wyatt and his students designed to meet FDA requirements. Generation 4 will be ready for animal trials this summer, and Generation 5 should be ready by June 2012. The aggressive fabrication work the Wyatt group is doing will give an entirely new set of capabilities to the developers of implants for purposes other than vision restoration.

Nanoscale Science and Engineering

The research of professor Karl Berggren and his students addresses sub-10-nm-length-scale fabrication and superconducting nanowire single-photon detectors. A highlight from the past year's work includes experimental results that so far qualitatively indicate that single-photon detectors based on ultra-narrow nanowires are more sensitive to low-energy photons than standard devices and suggests that their sensitivity may extend to mid-infrared wavelengths. Therefore, the Berggren group's devices are expected to be relevant for mid-IR photonics applications such as space communications, astronomy, chemical sensing, and failure analysis of low-voltage semiconductor electronics.

Professor Jing Kong is interested in the fabrication and applications of single-walled carbon nanotubes, graphene synthesis and transfer technology, and nanowire assembly and its applications. Highlights from her group's work during the past year include: the development of doped graphene electrodes for organic solar cells (in collaboration with professor Vladimir Bulovic); development of a solution-free, cost-effective, scalable technique for photocatalytic patterning of graphene; and an investigation of the roles of cations and anions with respect to the doping/dedoping mechanism of carbon nanotubes.

Photonic Materials, Devices, and Systems

Professor Vladimir Bulovic's laboratory is addressing a wide variety of research topics, including: the physical properties of organic thin films, structures, and devices; the physical properties of devices incorporating nanocrystal quantum dots; optoelectronics and electronics with nanostructured material systems; large-area electronics using organic and metal-oxide field effect transistors; hybrid organic/inorganic materials and structures; printed MEMS structures; and strong quantum electrodynamical coupling in organic thin-film structures. Notable accomplishments from the past year include work on the extension of the functionality of MEMS to different form factors — including large-area arrays of sensors and actuators — and to various substrate materials, by developing a means to fabricate large-area suspended thin films. Conventional photolithography-based MEMS fabrication methods limit the device array size and are incompatible with flexible polymeric substrates. Professor Bulovic and his students have developed a new method for fabricating sub-micron thick suspended metal films in MEMS using micro-contact printing. These films can be utilized in pressure sensors, microphones, deformable mirrors, tunable optical cavities, and large-area arrays of MEMS sensors. Their approach to MEMS fabrication involves the use of a stamp and a donor viscoelastic transfer pad that is coated with an organic release layer and a thin film of metal. The surface of this patterned stamp is placed in contact with the thin metal film on the donor transfer pad, and then the stamp is rapidly peeled away, picking up the metal film. The transferred metal films can bridge the gaps in the patterns of the stamp, forming a capacitive MEMS structure. Their MEMS printing process avoids the use of solvents and etchants, eliminating the need for deep reactive-ion etching and other harsh chemical treatments. Solvent absence during fabrication also avoids the detrimental effects of MEMS stiction that can result during wet processing. MEMS fabrication on flexible polymeric substrates is also possible due to the absence of elevated temperature processing.

Professor Qing Hu's research addresses the development of terahertz (THz) quantum cascade lasers and electronics, real-time THz (T-ray) imaging using quantum cascade lasers and focal-plane cameras, and high-power, mid-infrared quantum cascade lasers with high wall-plug efficiency. His THz quantum cascade lasers have achieved world-record performance in numerous respects, including but not limited to: the highest operating temperature in the pulsed mode (186 K without field and 225 K with magnetic field), highest operating temperature in the CW mode (117 K), highest power levels of approximately 250 mW, and the longest wavelength to date 190 μm (corresponding to 1.6 THz). The Hu group has performed real-time THz imaging at a video rate of approximately 20 frames per second. Another accomplishment includes the development of a novel tuning mechanism that is qualitatively different from all the other tunable lasers, and has achieved continuous tuning over a broad frequency range (approximately 330 GHz). These THz sources will be of great importance in opening up this spectral region for sensing, imaging, and high-bandwidth communications.

The overall focus of professor Erich Ippen's research continues to be the generation of femtosecond optical pulses and their application to science and technology. During the past year, the Ippen group has been developing compact fiber and waveguide lasers for use in advanced optical clocks and ultra-precise signal processing. Studies of materials and devices have been directed toward better understanding of silicon nanophotonic circuits. For optical comb and clock applications, high-repetition-rate femtosecond lasers with octave-spanning spectra are required. This year, the Ippen group achieved such operation at 1 GHz with an all-fiber system, a factor of 4 higher than previously demonstrated. Toward better understanding of the limitations and possibilities of silicon nanophotonics, they performed a detailed self-consistent study of nonlinear index changes and two-photon absorption in silicon nanophotonic circuits, and determined the dependence of free-carrier lifetime on proton bombardment dosage. For use in on-chip wavelength-division-multiplexing optical communication applications, they have demonstrated a high performance, precisely tuned and reconfigurable, wide-band 20-channel integrated optical filter bank. This is the largest-to-date reported number of channels built on a silicon-on-insulator platform. Professor Ippen's 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 Ippen group's studies and demonstrations (in collaboration with Franz Kaertner) of silicon nanophotonic circuits are of general importance to the advance on on-chip photonic communication and control, and are synergistic with the research of professor Michael Watts.

Professor Leslie Kolodziejski and Dr. Gale Petrich lead the integrated Photonic Materials and Devices group, whose research centers on fabrication of optoelectronic devices in III-V semiconductors. Active areas of research include the development of optical sources with emission wavelengths greater than 1.55 μm, the development of saturable Bragg reflectors for ultra-short pulse lasers and the development of an ultra-broadband optical modulator centered at a wavelength of 810 nm. A highlight from the past year's research is the observation of lasing in InP-based structures that were designed to emit at wavelengths of 1.75 μm, 1.85 μm and 1.95 μm, and the AlAs oxidation behavior in broadband saturable Bragg reflectors. 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 long-wavelength optical sources 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 Al_xO_y 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 longer in time.

The research program of professor Franz Kaertner focuses on low-noise femtosecond lasers and frequency combs, photonic analog-to-digital converters, femtosecond timing distribution in x-ray free-electron lasers, optical parametric chirped-pulse amplification to generate high-energy carrier-envelope phase-controlled pulses, and attosecond science. Key research accomplishments during the past year include a first-time achievement in scalable high-energy sub-cycle optical waveform synthesis that will enable many strong-field physics experiments. It also presents a new general path towards high peak-power laser technology operating at high repetition rate, i.e., high average power. Another key research accomplishment is the demonstration of both a bulk-optics photonic analog-to-digital converter (ADC) with record performance (7 bits at 40 GHz analog input signal) and an integrated-optics front end of a photonic ADC in a silicon-photonics platform. This shows that fully integrated photonic ADCs, perhaps surpassing current electronic technology by three orders of magnitude, are possible. This result is currently under review for publication in *Nature Photonics*.

Professors Marin Soljacic and John Joannopoulos work on theory and experiments for electromagnetic phenomena, especially those involving nanophotonics, nonlinear optics, and wireless power transfer. A key research highlight from the past year is the investigation of laser emission from optically-pumped rotationally-excited molecular gases confined in a metallic cavity. They have developed a theoretical framework able to accurately describe, both in the spatial and temporal domains, the molecular collisional and diffusion processes characterizing the operation of this class of lasers. The effect on the main lasing features of the spatial variation of the electric field intensity and the ohmic losses associated to each cavity mode are also included in their analysis. Their simulations show that, for the exemplary case of methyl fluoride gas confined in a cylindrical copper cavity, the region of maximum population inversion is located near the cavity walls. Based on this fact, their calculations show that the lowest lasing threshold intensity corresponds to the cavity mode that, while maximizing the spatial overlap between the corresponding population inversion and electric-field intensity distributions, simultaneously minimizes the absorption losses occurring at the cavity walls. The dependence of the lasing threshold intensity on both the gas pressure and the cavity radius is also analyzed and compared with experiment. Professors Soljacic and Joannopoulos have found that as the cavity size is varied, the interplay between the overall gain of the system and the corresponding ohmic losses allows for the existence of an optimal cavity radius that minimizes the intensity threshold for a large range of gas pressures. The theoretical analysis of this work expands the current understanding of lasing action in optically-pumped far-infrared lasers and, thus, could contribute to the development of a new class of compact far-infrared and terahertz sources able to operate efficiently at room temperature.

Physical Sciences

During the past year, professor Timothy Swager and his students have made a number of major accomplishments in the chemistry of nanocarbon materials. These include the demonstration of artificial-nose sensory devices capable of differentiating chemical vapors based on simple resistance changes, record low detection limits for the electrical detection DNA and a scalable technology for the formation of solutions of graphene layers. Additionally, they have demonstrated a new molecular approach to tailor materials interfaces in organic solar cells that produces greater efficiencies.

Professor Vladan Vuletic is interested in the experimental realization of quantum mechanical many-body states with quantum correlations (entanglement). Such states are at central to quantum information processing, quantum computing, and may result in improved performance of measurement devices, such as clocks, interferometers, gyroscopes. A key achievement of this past year is the demonstration of an optical nonlinearity at the single-photon level in which a single photon acts as a switch for another light beam. This relies on a novel effect that Professor Vuletic has experimentally demonstrated for the first time, in which a single photon induces transparency in an otherwise opaque atomic medium. These results can potentially be used to implement an all-optical transistor and quantum computing using photons.

Professor Martin Zwierlein is an experimentalist who is interested in the properties of ultracold gases of atoms and molecules as a universal test bed for condensed matter and nuclear theory. The interactions between atoms in his gases can be made as strong as quantum mechanics allows. Last year, his work focused on determining the universal thermodynamics of strongly-interacting Fermi gases, and studying spin transport and spin susceptibility in this form of matter. Spin transport was studied in an experiment called the “Little Fermi Collider,” a play on the Large Hadron Collider in CERN. Two gases of fermions (“spin up” and “spin down”) collide with each other with interactions as strong as Nature allows. Professor Zwierlein observed that the clouds, although they are a million times thinner than air, bounce off each other almost like billiard balls. At later stages, the spins very slowly diffuse into each other, with a universal diffusion constant given by Planck’s quantum h divided by the particle mass. From this observation, Professor Zwierlein, learned that from this diffusion he could also determine the spin susceptibility in these gases, for the first time, as a function of temperature. Spin susceptibility is an important quantity that allows him to see whether fermions have teamed up in pairs of opposite spin or whether they all share the same spin state. The importance of these experiments lies in the universality of the gas under study. The thermodynamics and strong inhibition to spin transport in an ultradilute atomic gas also describe neutron matter at densities 20 orders of magnitude higher. In work this past year, Professor Zwierlein, has observed the superfluid phase transition of a Fermi gas. The observation is like the famous lambda-transition of specific heat in helium-4. In his case, he measures the compressibility, related to the specific heat, and observes the transition to occur at a temperature of 0.165(10) times the Fermi temperature. This is the highest relative critical temperature of any known fermionic superfluid. It beats conventional superconductors, high-T_c superconductors, and helium-3. Professor Zwierlein's results can be directly compared to novel theoretical approaches that deal with strongly interacting fermions, and thus allow benchmarking of these theories. He hopes to gain a better understanding of how fermions behave under the influence of strong interactions. This will be very important in the design of new high-T_c superconductors that might one day improve energy efficiency.

The work of professor Abraham Bers centers on the analysis and simulation of stimulated Raman backscattering (SRBS) in intense laser-plasma interactions. His work is carried out in collaboration with scientists at the Lawrence Livermore National Laboratory (LLNL) in California. A key accomplishment of the past year is a new explanation of nonlinearly-generated electron acoustic waves observed in SRBS experiments. The results are applicable to understanding current laser-plasma experiments aiming to achieve ignition in the National Ignition Facility at LLNL. In other work, Professor Bers spent a great deal of time developing a new graduate-level textbook in high-temperature plasma physics and fusion plasma electrodynamics.

Quantum Computation and Communication

Professor Paola Cappellaro's 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. A first approach to accomplish these objectives is to use nuclear magnetic resonance (NMR) to study large quantum systems, comprising many nuclear spins, exploring coherence properties, control and noise reduction techniques. In the past year, her group has acquired a superconducting magnet and NMR spectrometer and developed homemade probes tailored to the study of crystals of Fluorapatite (FAp). This system is of particular interest because it presents a quasi-one-dimensional geometry that is amenable to study of quantum information transport and quantum simulation. Professor Cappellaro and her students have also studied theoretically the transport properties of spin chains in a thermal state: this regime has been often neglected in the literature, where pure-state chains have been usually considered. However, it is a regime that is more often encountered experimentally. They are currently implementing some of the protocols they devised using the FAp spins and the NMR setup. In a different, bottom-up, approach, Professor Cappellaro has studied a defect in diamond, the Nitrogen-Vacancy (NV) color center. The Cappellaro group has built a setup for the control of the NV electronic spin and nearby nuclear spin. They are also currently building a second setup that will focus on high-spatial resolution of optical excitation of NVs and on the control of nearby electronic impurities. Her group studied, with both simulations and experiments, the relaxation behavior of NV center ensembles, which is of fundamental interest for magnetometry as well as for quantum information processing. They are currently investigating novel approaches to DC magnetometry beyond the dephasing time limit. In the past year, Professor Cappellaro has developed a better understanding of quantum information transport as enabled by wires of nuclear spins at thermal equilibrium (thus in a highly mixed state). To fully exploit these systems, Cappellaro devised a procedure to encode a qubit of information into a pair of spins: this encoding enables in principle the perfect transfer of information via the spin wires, even when the spins are in the thermal state. Furthermore, the encoding and the use of thermal-state chains enable perfect transport even with the evolution that can be obtained from the naturally-occurring dipolar Hamiltonian by the experimentally-available control on the system. This result will be of importance in many proposed architectures for quantum computing, including one based on NV centers in diamond. A second result was a proposal for magnetometry based on ensembles of NV centers: this scheme would allow very high sensitivity, while combining high spatial resolution and large fields of view. When adding the bio-compatibility of diamond and operation at ambient conditions, the resulting magnetometer would find important applications in the bioscience, such as for the imaging of neuronal network dynamics.

Professor Jeffrey Shapiro and Dr. Ngai Chuen (Franco) Wong both lead the Optical and Quantum Communications Group. The ongoing focus for their work is to delineate the ultimate quantum limits on optical communication, imaging, and precision measurement systems, and, when these performance limits significantly exceed what conventional — homodyne, heterodyne, and direct detection — systems can provide, to find practical systems for approaching them. During the past year, progress was made in the following areas: techniques for obtaining spatial resolution that is superior to the standard Rayleigh bound; an architecture for physical simulation of the most powerful individual attack on Bennett-Brassard 1984 quantum key distribution; the theory of ghost imaging of rough-surfaced objects seen in reflection; theory and experimental demonstration of a quantum illumination protocol for secure communication; assessing the impact of multiple-pair emissions from a downconverter used as the source for entanglement distribution to remote atomic-ensemble memories; theory for the use of squeezed-vacuum injection and phase-sensitive amplification to improve the angular and range resolution of a coherent-state laser radar; development of waveguide downconverters as high-performance sources of entangled photon pairs; and demonstrations of spatial light-modulator (SLM) and computational ghost imaging. Professor Shapiro and Dr. Wong's work on sub-Rayleigh imaging is especially interesting. This study began with theory done — at a fundamental quantum level — for how nonclassical light might be used to sense finer spatial detail in an active-illumination imager than is available with a conventional light. The first practical approach that emerged from this analysis suggested the use of random scanning with a very tightly focused beam followed by *N*-photon detection. Through collaboration with researchers from the Politecnico Milano, they were able to demonstrate the predicted performance using their single-photon avalanche photodiode array. Later, they realized that a similar resolution improvement should accrue if they just applied thresholding to data collected with a conventional photo detector. This effect was also demonstrated experimentally. More generally, the progression from fundamental quantum analysis to practical realization that does not need special quantum sources or processing is something they have encountered before. Such techniques are called quantum mimetic, in that they mimic most of the advantages seen in quantum sensing systems with more practical classical light sources. In the past, they saw this to be true for optical coherence tomography, when they described and later demonstrated the quantum-mimetic technique they call phase-conjugate optical coherence tomography, which realizes the factor-of-two resolution improvement and immunity to group-velocity dispersion of quantum optical coherence tomography with a high-flux source that leads to reduced image-acquisition time. During the past year they realized another such quantum-mimetic technique in their SLM ghost imaging work, when they demonstrated operation with classical phase-sensitive light.

Appointments, Awards and Events

The following appointments, awards and events happened in AY2011.

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

Professor Elfar Adalsteinsson was granted tenure.

Professor Jing Kong was granted tenure.

Professor Collin M. Stultz was granted tenure.

Professor Michael Watts was appointed assistant professor and promoted to associate professor of electrical engineering.

Professor Anantha Chandrakasan, Joseph F. and Nancy P. Keithley Professor of Electrical Engineering, was appointed head of electrical engineering and computer science.

Professor Leslie A. Kolodziejski was appointed graduate officer of the electrical engineering and computer science department.

Professor Steven B. Leeb was appointed instructional labs office of the electrical engineering and computer science department.

Professor Jacob K. White was appointed co-education officer of the electrical engineering and computer science department.

Professor Isaac L. Chuang was elected a fellow of the American Physical Society.

Professor James G. Fujimoto was named the recipient of the 2011 Carl Zeiss Research Award.

Professors Martha Gray and Elfar Adalsteinsson were the founding leaders of the Madrid-MIT M+Visión Consortium. This program is a joint initiative between MIT and the Community of Madrid (one of Spain’s 17 autonomous communities, which includes the capital city of Madrid) and is designed to advance Spanish leadership and innovation in biomedical imaging research and practice. The Madrid-MIT M+Visión Consortium is a partnership of leaders in science, medicine, engineering, business, and the public sector dedicated to strengthening Madrid’s position as a global center of biomedical research by accelerating innovation in biomedical imaging, promoting translational research, and encouraging entrepreneurship.

Professor Martin W. Zwierlein received a Presidential Early Career Award for Scientists and Engineers.

Professor Mehmet Fatih Yanik received a National Institutes of Health Transformative R01 Program award.

Professor Martin W. Zwierlein received a Young Faculty Award from the Defense Advanced Research Projects Agency.

Professor Timothy K. Lu was named a TR35 Young Innovator by *Technology Review*.

The Center for Excitonics' video "Excited about Excitons" won an award for outstanding portrayal of young scientists in the Life at the Frontiers of Energy Research video contest.

Dr. Rod C. Alferness of Bell Laboratories, Alcatel-Lucent presented the Hermann Anton Haus Lecture.

Professor Vladimir M. Stojanovic received a Graduate Student Council Graduate Counselor Award.

Professor George C. Verghese was named a Margaret MacVicar Fellow.

Professor Jacob K. White received a Burgess and Elizabeth Jamieson Award for excellence in teaching.

Shanqing Cai, Lih Feng Cheow, and Faisal M. Kashif received Helen Carr Peake Research Prizes.

Jonathan Perry, John Z. Sun, and Da Wang were awarded Claude E. Shannon Research Assistantships for 2011-2012.

Krista Van Guilder received a 2010 American Graphic Design Award.

Mary Markel Murphy was appointed assistant director for administration and human resources.

Justin Wade was appointed assistant director for finance and sponsor relations.

Beverly Freeman was appointed majors programs coordinator.

Melissa Sheehan was appointed fiscal officer for post-award administration.

Cherry Mui was appointed financial assistant.

Mary Markel Murphy received a 2011 MIT Infinite Mile Award.

On April 30, 2011, RLE participated in MIT's "Under the Dome: Come Explore MIT!" event. This celebration was a day-long, campus-wide open house for the local Cambridge community. Children and their families explored exhibits and demonstrations that represented MIT's 150 years of innovation in science and engineering. Students from the research groups of Professors Vladimir Bulovic, Steven Leeb and Yoel Fink provided demonstrations in molecular electronics, robotics, and lasers.

Sadly, this past year, RLE suffered the loss of Donald E. Troxel, professor emeritus of electrical engineering who passed away on January 18, 2011. The late Professor Troxel was an MIT alumnus who spent 40 years at the Institute as an electrical engineering faculty member and principal investigator at RLE and the Microsystems Technology Laboratories.

Affirmative Action and Outreach Activities

RLE has worked and will continue working to increase the number of women and minorities in career positions in the laboratory, in the context of the limited pool of qualified technical applicants and the unique qualifications of RLE's sponsored research staff. Specific measures will include maintaining our high standards for recruitment procedures, among them sending job postings to minority colleges and organizations, working closely with the RLE faculty/staff supervisor at the beginning of each search to identify ways of recruiting minority and women candidates for the new position, and being committed to finding new techniques to identify women and minority candidates more effectively. During the past year, RLE has appointed three women to exempt-level staff positions in headquarters.

RLE has continued its work in nurturing future generations of engineers and scientists, RLE, under the sponsorship of the NSF grant program, offered a special summer program in Quantum Information Science for Undergraduates for up to 20 students. The course was developed for undergraduates about to enter their senior year who seek a basic knowledge of quantum information processing. In addition to receiving classroom instruction, students toured laboratories, and interacted with MIT graduate students, postdoctoral fellows and faculty who work on quantum information processing. The principal teaching faculty were top MIT research investigators in this field: professors Isaac Chuang, Seth Lloyd, and Jeffrey Shapiro whose groundbreaking work has already influenced this growing field in significant ways. The program covered tuition costs for participants.

The Center for Ultracold Atoms (CUA) conducted a program to stimulate the careers of undergraduate physics majors who are thinking of becoming teachers in the physical sciences at the pre-college level. Called Teaching Opportunities in the Physical Sciences (TOPS), the program involved eight undergraduate physics majors, typically juniors, who were recruited from colleges and universities across the nation. These students worked in teams with two master teachers. The central activity in TOPS was the experience of actual teaching. Two teams of four students each worked under the direction of a master teacher to prepare and teach students at both the middle school and high school levels. The middle school classes were at the Museum of Science summer school program while the high school students were recruited from local high schools. The program was free to the students. This was the third summer in which CUA ran the program.

Jeffrey H. Shapiro
Director
Julius A. Stratton Professor of Electrical Engineering