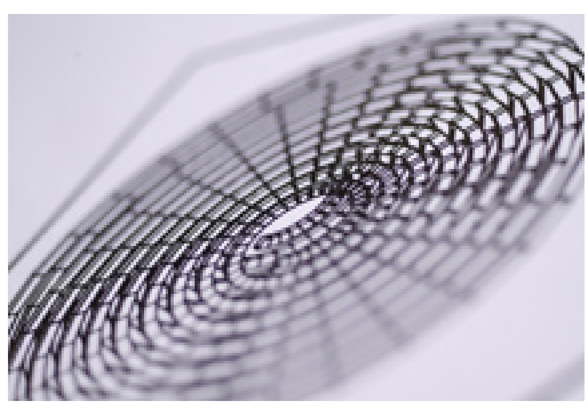
# Research Laboratory of Electronics


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 50 faculty members who are affiliated with the Departments of Electrical Engineering and Computer Science, Physics, Mechanical Engineering, Materials Science and Engineering, Mathematics, the Biological Engineering Division (BE), the Engineering Systems Division, and the Harvard-MIT Division of Health Sciences and Technology. During the past year, approximately 250 graduate students and 60 undergraduates from nine MIT departments pursued research within RLE. The research is supported primarily by Department of Defense agencies, the National Institutes of Health, the National Science Foundation, the Department of Energy, 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 consists of six major interrelated groupings: circuits, systems, signals, and communications; physical sciences; quantum computation and communication; nanoscale science and engineering; photonic materials, devices, and systems; and communication biophysics.

Detailed information about RLE research in the AY2006 can be found in RLE Progress Report No. 148. The report is available online at http://www.rle.mit.edu/media/media_pr.html. What follows is a summary of research highlights from the past year.

## Circuits, Systems, Signals, and Communications

Professor Jacob White uses a range of engineering design applications to drive research in simulation and optimization algorithms and software. As part of the Singapore-MIT Alliance Program on Computational Engineering, Professor White and his collaborators have been developing numerical techniques for use in biomolecule design and systems biology, as well as design tools for bio-microelectromechanical (bio-MEMS) devices. They have recently reported a



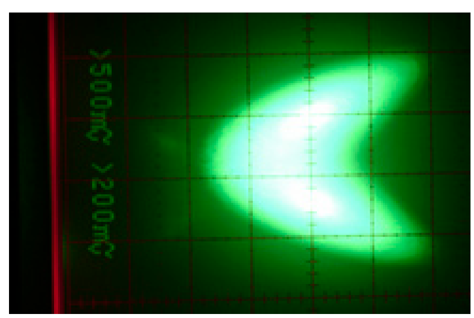
fast boundary-element method algorithm that is well suited for solving the electrostatics problems that arise in bio-MEMS design.

Professor Luca Daniel leads research ranging from the development of full-wave integral equation electromagnetic field solvers for on-chip interconnects and power distribution grids to the development of techniques for generating parameterized reduced-order models of linear and nonlinear dynamical systems. During the past year his field-solver research has led to a new set of basis functions for discretizing the cross sections of interconnect wires, producing a well-conditioned system whose dimensionality is more than a factor of ten smaller than that of the usual piecewise constant basis functions.

Professor Jae Lim's Advanced Telecommunications and Signal Processing group participated in the design of the Grand Alliance digital high-definition television (HDTV) system, which served as the basis for the US digital television standard adopted in 1996 by the Federal Communications Commission. Since then, Professor Lim has focused his efforts on making improvements to digital television, as well as other real-world problems in audio and digital communications. His current work has led to the development of a new approach to suppressing blocking-artifacts in image and video compressions systems, such as those used to reduce the bandwidth needed for communication and the storage required for video recording systems.

The research of Professor Vivek Goyal and his students focuses on novel representations of information and algorithms to enable economical data acquisition. Their work in both of these areas exploits the compressibility of a signal in the acquisition stage, a topic often known as compressed sensing, and it relies on parametric representations that are not bound to traditional linear time-invariant (Fourier domain) approaches. Thus, for example, by compressing sets instead of sequences, they have developed important new source coding results for lossless compression, universal lossless compression, and rate-distortion theory. Likewise, for analog-to-digital conversion, they have developed new algorithms for mitigating timing noise that provide great improvements over the best possible linear time-invariant processors.

Professor Alan Oppenheim's Digital Signal Processing group continues to work on a broad array of problems in the area of signal processing and its applications. A primary focus is on algorithm development in general, with applications serving as motivating contexts. Approaches to new algorithms have come from unconventional directions, such as fractal signals, chaotic behavior in nonlinear systems, and quantum mechanics. A recent example has been the study of using deterministic chaos from the Lorenz system to generate the quasi-orthogonal, high-bandwidth signals that would enable multiple radars to share the same frequency band.



Professor Gregory Wornell is interested in the algorithmic and architectural aspects of the design of multimedia networks, wireless communication and sensor networks, and reliable circuits and microsystems. During the past year he has developed new low-complexity capacity-achieving rateless codes for Gaussian channels. These include an ultraefficient finite-layer construction, and a construction for multiple-access channels. In other work, he has found efficient blind-calibration algorithms for very high-speed time-interleaved analog-to-digital converters that dramatically improve the effective number of bits while requiring no training and only a modest amount of computation.

Professor David Staelin has been studying the spectral efficiency of interference-limited ad hoc wireless networks. In theoretical work he has shown that, in extreme multipath conditions, this efficiency improves if nodes without channel state information transmit using the optimum number of antennas instead of equal power from every available antenna, which is the optimum greedy strategy. Experimental observations have just begun, using an 802.11, 2.4 GHz software receiver developed within his group. Together with Dr. Philip Rosenkranz, Professor Staelin also works on the development of instruments and algorithms for retrieving atmospheric and surface parameters from data collected by airborne or satellite sensors. Recent achievements include matching 15-km resolution, 50-191 GHz radiances from an operational National Oceanic and Atmospheric Administration satellite to a mesoscale atmospheric model, and demonstrating improved agreement between Aqua spacecraft brightness-temperature measurements and radiosonde data. The latter comparison used an algorithm developed by Dr. Rosencranz that is part of NASA's operational software package.

Professor Rahul Sarpeshkar is pursuing a collection of projects in biologically-inspired electronics, including a novel companding algorithm for improved hearing in noise, a radio-frequency cochlea that is inspired by the human ear, an ultra energy-efficient analog-to-digital converter inspired by neuronal spiking, and an ultra low-power pulse oximeter built with bio-inspired photoreceptors. In other work, he has proposed a model that explains how fast (100 kHz) cochlear amplification is possible given the slow (1 ms) time constant of the outer hair cells in the ear.

Professor Vladimir Stojanovic has research interests that lie in the design, analysis, and optimization of integrated circuits and systems with the specific goal of breaking the hierarchical separation that inhibits vertical system optimization in power-constrained integrated circuits. His current projects include establishing a tighter connection between constrained on- and off-chip communication circuits and systems, and introducing the power of distributed convex optimization in system description and partitioning. A key achievement from this year—made in collaboration with his students and Professor Joel Dawson of the Microsystems Technology Laboratories (MTL)—is the identification of a set of essential heuristics for a geometric programming CMOS-circuit optimization tool.

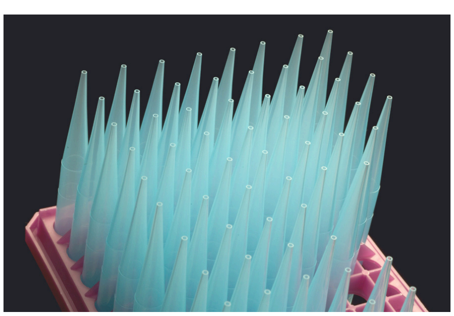
Professors Anantha Chandrakasan and Donald Troxel have been working to further the use of field-programmable gate arrays (FPGAs) for custom application implementations. In one study, they modified a public-domain FPGA place-and-route tool in such a way that it reduced power consumption by 50 percent with an area overhead of less than 10 percent. In other work, they have been exploring the benefits—in performance and power consumption—of 3-D integration in FPGAs.

Professor John Wyatt's long-term goal is the development of a chronically implantable wireless retinal implant to restore some level of useful vision to patients with outer retinal diseases, such as retinitis pigmentosa or macular degeneration. During the past year, his group has developed a wireless device that works in a waterproof coating that protects it from physiological saline.


Professor Elfar Adalsteinsson's Magnetic Resonance Imaging (MRI) group is addressing methods for in vivo acquisition, reconstruction, and processing of medical imagery via magnetic resonance. Projects that are under way include the development of efficient encoding for in vivo spectroscopic imaging with radio-frequency coil arrays, enhanced estimation of low signal-to-noise ratio brain metabolites via incorporating information from high-resolution structural imaging, and radio-frequency array technology for magnetic-resonance signal excitation that could solve a severe inhomogeneity problem currently plaguing high-field MRI systems.

Professor Joel Voldman's research interest is the development of microsystems for manipulating and measuring from cells. For this work, he draws upon the technologies of microfluidics and electrical trapping. During the past year he has developed a new cell-patterning technique that can be used to pattern stem cells on arbitrary surfaces, allowing, for the first time, studies of cell interactions during the initial stages of colony formation. He has also conclusively demonstrated that his patented iso-dielectric cell-screening tool can separate cells based upon electrical differences alone, and he has successfully scaled up his row-column addressable dielectrophoretic cell-trapping array to the point that it will be useful for performing biological assays.

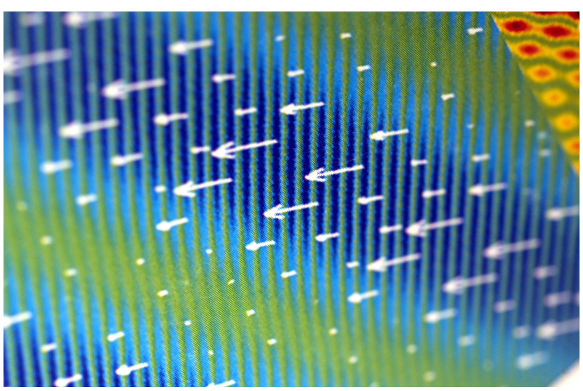
The work in Professor Jongyoon Han's Micro/Nanofluidic Bio-MEMS group is focused on the development of novel microfluidic and nanofluidic devices and systems for proteomic sample preparation. In collaboration with Professor Steven Tannenbaum of BE, he is coupling his advanced sample-preparation microdevices to mass spectrometry biodetection for improved detection sensitivity and selectivity. In collaboration with Professor Scott Manalis of BE, he is integrating his nanofluidic preconcentrator with a suspended microchannel-resonator biosensor, with the goal of developing a microdevice for cancer biomarker detection.



## Physical Sciences

Professor Vladan Vuletic is interested in new methods for manipulating atoms and light in a regime wherein quantum mechanical aspects dominate their behavior and properties. His group tries to realize new nonclassical light sources, as well as quantum mechanical many-body states, for tasks in quantum information science and precision measurements. During the past year he has developed a high-brightness source of narrowband pairs of identical photons using cold atoms. This source, which can be used for distributed quantum computation and for quantum teleportation, operates near the fundamental brightness limit set by its spectral width.

Professor Wolfgang Ketterle's research concentrates on the properties of Bose-Einstein condensates (BECs) and degenerate Fermi gases, the use of ultracold atoms for precision measurements, and the study of many-body physics through experiments with quantum degenerate gases. A major new result from the past year is his demonstration of fermionic superfluidity in a system with imbalanced populations of spin up and spin down fermions. These systems are likely to provide new insights into the phenomena of superfluidity and superconductivity. In other work, done in collaboration with Professor David Pritchard, he has taken an important step towards compact matter-wave sensors by observing interference between BECs that were split with an atom chip. They have also shown the value of applying precision methods of atomic physics to problems in condensed matter physics by using microwave spectroscopy to characterize the superfluid to Mott insulator transition of a BEC in an optical lattice.



Professor Jin Kong's research on electromagnetics addresses a variety of problem areas, including left-handed metamaterials, ultra-wideband coherent processing of multiple radar signals, unexploded ordnance detection, and modeling the trapping and binding forces between particles. A key research highlight from the past year is his work showing that left-handed metamaterials can be made active by inserting varactor diodes into existing designs. This result is extremely important because it offers tremendous control over the material parameters and has direct application to antenna and radome design.

Professor Abraham Bers is engaged in theoretical research on plasma electrodynamics and its applications. During the past year, his efforts have focused on modeling and understanding some aspects of intense laser-plasma interactions that are of interest to inertial confinement energy generation. In particular, stimulated Raman backscattering and associated simulated electron-acoustic scattering were studied in relation to experiments carried out at the Los Alamos National Laboratory and for future relevance to the National Ignition Facility at the Lawrence Livermore National Laboratory.

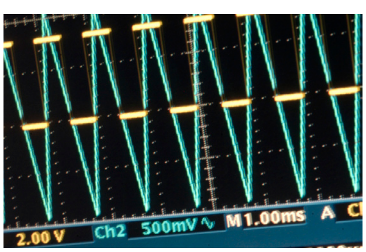
## Quantum Computation and Communication

Professor Seth Lloyd investigates methods for constructing quantum computers and quantum communication systems using atomic physics, quantum optics, and superconducting electronics, and he collaborates with experimental groups at MIT and elsewhere in these areas. During the past year he has continued his investigation of the classical and quantum communication capacities of quantum channels, showing, among other things, how quantum channel capacity can be enhanced using prior shared entanglement. He has also been investigating the ultimate physical limits to the accuracy of sensing and measurement that are set by the laws of quantum physics.

The research in Professor Isaac Chuang's group is aimed at harnessing the resources of quantum physics for novel information technology capabilities. Toward that end, they are working on quantum information theory and atomic physics implementations of basic quantum gates. During the past year they have implemented a quantum simulation of a superconductivity model, and established new theoretical bounds on the feasibility of quantum simulations. They have also succeeded in realizing a new surface-electrode ion trap chip that, in addition to its relevance to quantum computation, may have potential applications in chemical analysis.

Professor Jeffrey Shapiro and Dr. Franco Wong lead the Optical and Quantum Communications group, which has been working on the generation of entangled photons and their applications in quantum communications and quantum cryptography. During the past year they have continued development of high-flux sources polarization-entangled photons based on bidirectionally pumped parametric down-converters. One such source relies on a polarization-Sagnac interferometer to produce high-quality polarization-entangled photon pairs without active phase stabilization. This source was used in a recent experiment that demonstrated the Fuchs-Peres-Brandt (FPB) probe—the most powerful individual attack on the Bennett-Brassard 1984 quantum key distribution protocol. The FPB probe experiment employed single-photon two-qubit quantum logic gates that were previously developed by the group.

Professor Terry Orlando is using superconducting circuits as components for quantum computing and as model systems for nonlinear dynamics. The goal of the present research is to use superconducting quantum circuits to realize a fully functional quantum bit (qubit), to perform measurements on qubits, to model the sources of qubit decoherence, and to develop scalable quantum algorithms. The particular device being studied is made from a loop of niobium interrupted by three Josephson junctions, which stores a persistent-current qubit. During the past year he has used a trilayer optical lithography process to



create deep-submicron Josephson junctions. These junctions are required to realize large qubit tunnel-coupling that, in turn, allow improved immunity to dielectric-induced decoherence so that there is no foreseeable barrier to large-scale integration. He has also demonstrated Mach-Zehnder interferometry of the persistent-current qubit, obtaining experimental results that exhibit remarkable agreement with theory.

## Nanoscale Science and Engineering

Professor Henry Smith directs the NanoStructures Laboratory, whose dual mission is the development of advanced nanofabrication technology and the application of that technology to research in optical, electronic, and magnetic devices. An example of his development of advanced nanofabrication technology is his demonstration of a new approach to photolithography that has the potential to enable molecular-level resolution using 400-nm-wavelength radiation. An example of his optoelectronics research is the bank of ring-resonator filters that were fabricated for the 39 Gs/s, 7.5-bit optical bit-interleaved analog-to-digital converter that is being developed in collaboration with Professors Franz Kärtner, Erich Ippen, Judy Hoyt, Michael Perrott, and Rajeev Ram and researchers at MIT Lincoln Laboratory.

Research in Professor Karl Berggren's Quantum Nanostructures and Nanofabrication group during the past year has focused on developing a nanometer-length-scale single-photon detector, and new lithography methods employing sequential imprints with nanometer-length-scale features. They have demonstrated world-record detection efficiency in a superconducting nanowire single-photon detector at 1.55-μm optical wavelength, and they have developed new understanding of its reset time, which can be as short as 1 ns, depending on the device area. This single-photon detector is likely to find applications in interplanetary high-data-rate optical communication systems, high-data-rate quantum key distribution systems, circuit analysis and diagnostic systems, and imaging of biological processes in living tissue.

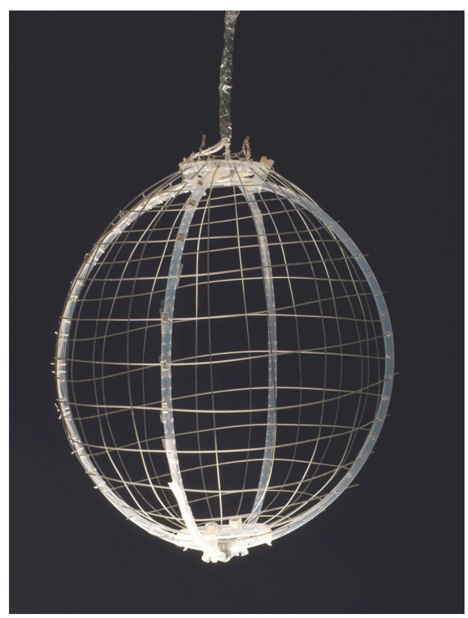
Professor Jing Kong is interested in the fabrication and applications of carbon nanotubes. A key objective of her program is to understand how the synthesis conditions in growing a nanotube affect its chirality and conduction behavior (metallic versus semiconductor). Toward that end, she has developed a tunable Raman spectrometer that enables her to analyze the chirality distribution of the nanotubes she synthesizes, and she has developed a synthesis procedure that employs a novel gold nanoparticle catalyst. In future work, she plans to develop a series of alternative metal-species catalysts and use her spectrometer to compare the chiralities of nanotubes grown using these different catalysts.

## Photonic Materials, Devices, and Systems

Professor Leslie Kolodziejski and Dr. Gale Petrich are working on the design, fabrication, and characterization of photonic integrated circuits. They hope to demonstrate ultrafast optical logic functionality as well as to implement photonic crystal technology, and thus to improve performance while reducing size or increasing the density of integrated devices. In collaboration with Professors Erich Ippen, John Joannopoulos, and Marin Soljacic, they recently demonstrated supercollimation of an optical light beam over a macroscopic distance using a photonic crystal structure. Whereas the input beam to their supercollimator would have suffered substantial diffraction spreading within a few microns of propagation in an isotropic medium, this beam maintained its beam size over an 8-mm-long path within their photonic-crystal supercollimator.

Professor Erich Ippen has continued his work on the generation and application of ultrashort optical pulses, while expanding his efforts in the areas of micro- and nanophotonics. Together with Professors Franz Kärtner and Henry Smith, he has demonstrated a densely integrated polarization-independent optical add-drop multiplexer using high-index contrast photonic circuits. Using a new highly nonlinear (bismuth-oxide based) optical fiber, he has obtained laser action with a smooth, ultrabroadband femtosecond spectrum that is suitable for spectrally sliced optical communications and diagnostics. Professor Ippen is also the principal investigator for a major new program on optical arbitrary waveform generation, whose goal is to provide dramatically new capabilities for optical signal processing, communications, lidar, and sensing.

Professor Yoel Fink is pursuing the theory, design, process development, and characterization of novel structured composite fibers with engineered electronic, photonic, and phononic properties that follow from their mesoscale features. Among his most exciting recent advances is the development of a sophisticated optical system made of mesh-like webs of light-detecting fibers. These fiber constructs, which have a number of advantages over their lens-based predecessors, are currently capable of measuring the direction, intensity, and phase of light without the lenses, filters, or detector arrays that are the classic elements of optical systems such as eyes or cameras. Moreover, a fiber web in the shape of a sphere can sense the entire volume of space around it.



Professor Franz Kärtner is working on ultrashort-pulse generation in the few-cycle regime, with applications in frequency metrology, as well as high-density integrated optics made of high-index contrast silicon waveguides, and large-scale timing distribution and synchronization of multiple laser sources and radio-frequency signals.

During the past year he has demonstrated a balanced optical-to-radio-frequency (RF) phase detector for femtosecond synchronization of RF signals to optical pulse trains. He has also developed a new pulse characterization method, called two-dimensional spectral shearing, for the measurement of single-cycle pulses without the need for calibration. His work is relevant to large-scale timing distribution, advanced optical clocks, and high-resolution laser spectroscopy.

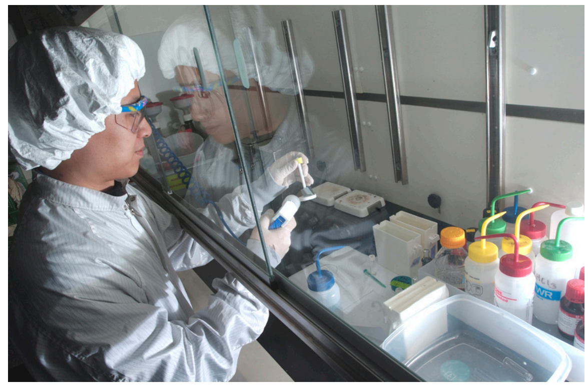
Professor James Fujimoto divides his research efforts between two areas: biomedical optical imaging and diagnostics, and ultrashort-pulse laser technology. He continues to pioneer optical coherence tomography (OCT), a field created by his group in 1990. OCT is an emerging medical imaging technology analogous to ultrasound. In recent bioimaging work, Professor Fujimoto and his collaborators have made significant advances in both the technology and medical applications of OCT. Specific achievements include clinical OCT endoscopic imaging studies at the Veterans Administration Medical Center to investigate early visual cancerous changes in the gastrointestinal tract and development of optical coherence microscopy (OCM)—a complementary imaging modality to OCT—and its use on pathology specimens for cancer detection applications. In his ultrashort-pulse laser research, Professor Fujimoto has been developing high-speed frequency swept lasers, which have applications in metrology and spectroscopy and also enable dramatic speedups (approximately 100x) in OCT imaging.

Professor Steven Johnson's research is two pronged: he works on problems of wave propagation in nanostructured materials, primarily photonic crystals, and he has

developed and continues to improve one of the most widely used software libraries for fast Fourier transforms ("the fastest Fourier transform in the West"). One of his recent accomplishments, made in collaboration with Professor John Joannopoulos, was to demonstrate, through numerical simulations, that the radiation from an oscillating dipole moving within a photonic band-gap crystal may exhibit anomalous effects in the sign and magnitude of the Doppler shifts both inside and outside the gap. This effect could be used to identify the physical origin of the backward waves in metamaterials.

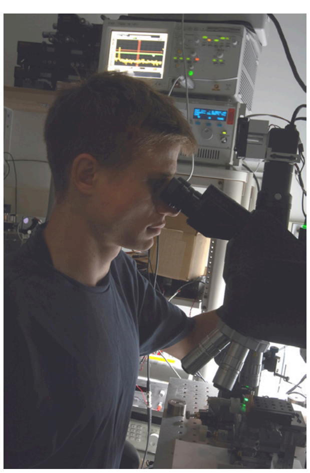
Professor Marin Soljacic is interested in nanophotonics and nonlinear optics. Recently, he has performed a detailed theoretical study of how nanostructuring of materials can dramatically modify their thermal emission properties. He has also performed a quantum field analysis of the use of electromagnetically-induced transparency, together with photonic crystal microcavities, to enable optical nonlinearities at the single-photon level. His work on tailoring thermal emission properties will be of interest to the defense community, and his research into single-photon nonlinearities is relevant to all-optical quantum information processing.

Professor Marc Baldo is interested in electronic and optical processes in molecules, especially as applied to organic solar cells and light-emitting devices. Recently, he demonstrated a method for controlling the spin of the excited states in optical light-emitting diodes, which is something of a holy grail in the field because it provides the means to significantly increase the emission efficiency of any organic material. He also implemented a photosynthetic architecture in solar cells that differs from the regular structure by separating the optical and electrical functions of the cell. This structure has been predicted to reach power conversion efficiencies as high as twice the current state of the art.



Professor Vladimir Bulovic's laboratory is addressing a wide variety of topics related to hybrid organic/inorganic optical and electronic devices. Recent achievements include red-green-blue quantum-dot light-emitting diode (QD-LED) pixels with pixel sizes as small as 25 μm and printed QD patterns as small as 150 nm; QD-LEDs with external quantum efficiencies exceeding 2.5 percent; white QD-LEDs that contain multiple QD lumophores in a single QD monolayer; and the first microcavity QD-LED, which exhibits directional emission. In addition to the preceding work—which already opens up vast possibilities for display technology—Professor Bulovic has also demonstrated J-aggregate films with record high absorption constants when inserted in a critically-coupled resonator structure, and, in collaboration with researchers at Hewlett Packard, he has developed and demonstrated a method for printing organic thin film structures with 30 μm resolution that constitutes an essential step toward the production of integrated organic electronics on flexible substrates.

Professor Qing Hu's research is focused on the development of terahertz (THz) lasers and real-time THz (T-ray) imaging. His THz quantum cascade lasers have achieved world-record performance in many respects: the highest operating temperature in the pulsed mode (164 K), the highest operating temperature in continuous-wave mode (117 K), the highest power levels (250 mW), and the longest wavelength (178 μm). Recently, he has performed T-ray imaging at a video rate of approximately 20 frames/second using one of his sources. More generally, these THz sources will be of great importance in opening up this spectral region for sensing, imaging, and high-bandwidth communications.

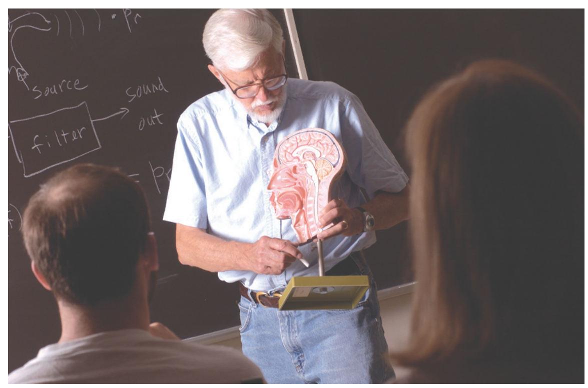


Professor Rajeev Ram's Physical Optics and Electronics group has three primary themes: integrated photonics, biophotonics and bioprocesses, and thermodynamics of semiconductor devices. During the past year they have demonstrated a record high density growth of microbial cells in a "lab-on-a-chip." This experiment validates the utility of a new platform they have developed for microbial cell culture, whose applications range from vaccine and biomaterials production to basic science studies of the mechanisms for intercellular communications. In other work, they have demonstrated nonreciprocal Faraday rotation in an InP waveguide. This is the first demonstration of nonreciprocal behavior in a semiconductor. Because the Faraday rotator is the only optics component that had never been miniaturized onto a semiconductor chip, their work represents a critical step toward the realization of large-scale photonic integrated circuits.

Professor Peter Hagelstein works on a variety of applied problems relating to an unconventional approach to energy generation, as well as the general problem of thermal-to-electrical energy conversion. His recent research includes modeling the voltage enhancement seen in InSb thermal diodes, and developing a new model for a novel quantum-coupled, single-carrier, thermal-to-electrical energy converter. He has also been working with a Canadian company to test a prototype cold fusion reactor that is based on the Yang–Koldomasov effect.

## Communication Biophysics

Professor Kenneth Stevens leads a research group whose goal is to develop models that explain how listeners extract discrete sounds and words from continuous speech despite large variations in the acoustic representations of these units for different speech sounds, talkers, and manners of speaking. Their approach is to identify certain invariant acoustic attributes that are language independent and are products of the anatomy and physiology of human sound generation and perception capabilities. The model then identifies further attributes that are specific to the language and attributes that are speaker dependent. The results of this research will find application in the development of improved algorithms for the synthesis of speech from text and for automatic speech recognition. They are also relevant to the interpretation of disorder in speech production.




Professor Louis Braida's research has as its long-term goal the development of improved hearing aids and cochlear implants. Specific goals for his work include evaluating the effects of the style of speech articulation on speech reception by the hearing impaired, developing accurate analytic models to predict the effects of speech-signal alterations on intelligibility, and developing signal processing techniques that will increase the effectiveness of hearing aids. A major focus of his recent work has been developing speech-based speech-transmission index (sSTI) metrics that, unlike previously-proposed sSTI metrics, can successfully predict intelligibility of speech that has been subjected to nonlinear processing, such as occurs in amplitude-compression hearing aids, noise-reduction algorithms, and cochlear-implant speech processors.

The long-term goal of Dr. Charlotte Reed's research is the development of tactual aids that can serve as hearing substitutes for persons who are profoundly deaf or deaf-blind. More generally, her research is relevant to the development of improved tactual and haptic displays for a broad class of applications, including virtual environment and teleoperator systems. During the past year, she has continued hardware and software development for an upgraded tactual stimulating device, namely a three-finger display capable of presenting a broad range of tactual movement to the human fingers. In more fundamental work, Dr. Reed has completed a series of experiments that assessed the discrimination of temporal onset order of the tactual sense, a topic which is motivated by her work on the tactual presentation of a temporal cue to consonant voicing as a supplement to lipreading.

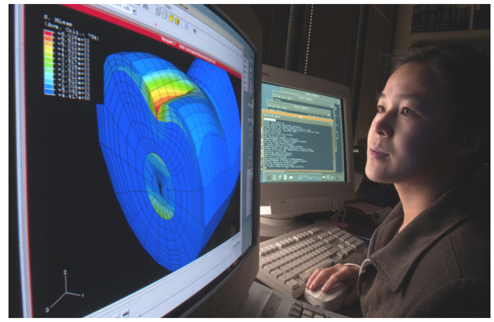
Dr. Bertrand Delgutte is a member of the Eaton-Peabody Laboratory of Auditory Physiology and Dr. Donald Eddington heads the Cochlear Implant Research Laboratory at the Massachusetts Eye and Ear Infirmary. Their collaborative research has a major focus on physiological studies aimed at improving bilateral cochlear implants. In recent neural coding studies of interaural time differences (ITDs) they have shown that neural ITD sensitivity to the carrier of amplitude-modulated waveforms is much more precise than its sensitivity to the envelope. Their result suggests that current cochlear processors—which code ITD information in the envelope of modulated pulse trains—should be modified to more effectively deliver this information.

Professor William Peake has conducted a hearing sensitivity study on one species of wild cat—the sand cat, found in the deserts of North Africa and Asia—and found, from measurements on 25 sand cats and 8 non-sand cats, that the former's ears are more sensitive than those of other species. The acoustic properties of the ears did not, however, indicate that hearing threshold is correlated with acoustic power absorption.

Dr. Joseph Perkell has two principal projects underway—Constraints and Strategies in Speech Production, and The Effects of Hearing Status on Adult Speech Production—both of which could have long-term applications in diagnosing and treating communication disorders. A recently completed experiment, guided by a model of speech motor control, studied the effects of speaking condition and hearing status on vowel production by postlingually deafened adults in comparison with normal-hearing speakers. The results obtained led to the inference that spectral and durational distinctions in first-to-second formant vowel contrast are not dependent on hearing status.

Professor Dennis Freeman made further advances in his work investigating the way the inner ear processes sound. During the past year he demonstrated a new technique for imaging and measuring the motion of structures in the inner ear. The technique combines the imaging capabilities of OCM with the motion measurement capabilities of heterodyne laser Doppler velocimetry. He has used this technique to image all of the structures in the inner ear of a gerbil, and he has also demonstrated the ability to measure subnanometer motions of all these structures in an in vitro preparation.

Dr. Mandayam Srinivasan directs the Laboratory for Human and Machine Haptics, known less formally as the Touch Lab. Its work is guided by a broad vision of haptics



including all aspects of information acquisition and object manipulation through touch by humans, machines, or a combination of the two. Recent research highlights from the Touch Lab include the design, fabrication, and testing of a 150-µm-thick optical pressure sensing device that is suitable for fundamental studies of skin mechanoreceptors, and the development of an interface and virtual-reality system—employing 3-D haptic and audio feedback—with which blind users can interact with and explore virtual models of real spaces before actually encountering them.

The research of Dr. Stefanie Shattuck-Hufnagel concerns three aspects of speech production: the nature of American English intonational prosody, the effect of prosodic structure on phonetic word-form variation, and patterns in spoken errors. A particularly significant effort—which began this year, with her training of 12 undergraduate students as Tone and Break Indices "labelers"—is the development of the first prosodically labeled corpus of spontaneous Maptask speech in American English. This corpus, once it is complete, will enable the study of the effects of prosodic structure and prominence on word-form variation.

## Center for Integrated Photonic Systems

The Center for Integrated Photonic Systems (CIPS) was created as an MIT virtual center in 2004 with seed funding and administrative support from RLE. Professor Rajeev Ram of RLE is the CIPS director, and Dr. Frederick Leonberger is the CIPS senior advisor. The CIPS charter calls for exploration of advanced technologies and strategies that enable integrated photonic devices, modules, and systems to provide breakthrough capabilities for a variety of future system applications ranging from communications to sensing. Its specific objectives are to provide leadership and direction for research and development in photonics, to foster an Institute-wide community of researchers in the field of integrated photonics and systems, and to integrate member companies into the MIT photonics community. The third CIPS annual meeting, which was held in May 2006, attracted representatives from more than 30 photonics companies and featured plenary talks by Dr. Michael Lebby (president, Optoelectronics Industry Development Association), Professor Alan E. Willner (University of Southern California, president of the Institute of Electrical and Electronics Engineers [IEEE] Lasers and Electro-Optics Society), and Dr. Thomas G. Giallorenzi (head of Optical Sciences, Naval Research Laboratory).

## Appointments, Awards, and Events

The following appointments and awards were made in AY2006.

Dr. Mehmet F. Yanik was appointed assistant professor of electrical engineering.

Professor Anantha P. Chandrakasan was appointed director of MTL.

Professor John Joannopoulos was appointed director of the Institute for Soldier Nanotechnologies.

Professor Dennis M. Freeman was promoted to professor of electrical engineering.

Professor Yoel Fink received tenure.

Professor Rahul Sarpeshkar received tenure.

Professor Marc A. Baldo was promoted to associate professor of electrical engineering.

Professor Jongyoon Han was promoted to associate professor of electrical engineering and biological engineering.

Professor Joel Voldman was promoted to associate professor of electrical engineering.

Professor Vladimir M. Stojanovic was appointed Henry L. and Grace Doherty assistant professor of electrical engineering and computer science.

Professor Dennis M. Freeman was named a Margaret MacVicar Faculty Fellow.

Professor Wolfgang Ketterle was appointed associate director of RLE.

Professor Rajeev Ram was appointed associate director of RLE.

Professor James G. Fujimoto was elected to the National Academy of Sciences.

Professor Erich P. Ippen received the 2006 Frederic Ives Medal of the Jarus W. Quinn Endowment from the Optical Society of America.

Professor Jin A. Kong was selected to receive an honorary doctorate from the Université de Nantes.

Dr. Frederick J. Leonberger received the 2006 Photonics Award from the Lasers and Electro-Optics Society of the IEEE.

Professor Qing Hu was elected a fellow of the Optical Society of America.

Professor Alan V. Oppenheim received the 2005 Signal Processing Education Award from the Signal Processing Society of the IEEE.

Professor Emeritus John M. Wozencraft received the 2006 Alexander Graham Bell Medal from the IEEE.

Professor H. Jeff Kimble presented the Hermann Anton Haus Lecture.

Professor Vladimir Bulovic received a 2006 Ruth and Joel Spira Award for Teaching Excellence.

Professor Alan V. Oppenheim received the 2006 EECS Graduate Student Association Award for Best Counseling.

Professor Joel Voldman received a Department Special Recognition Award for his contributions to the Graduate Admissions Program.

David E. O'Gorman received the 2006 Helen Carr Peake Research Prize.

Radha Kalluri and Jocelyn E. Songer received honorable mentions in the 2006 Helen Carr Research Prize competition.

Joseph F. Connolly, James M. Daley, Mark K. Mondol, and Maxine Samuels received 2006 MIT Infinite Mile Awards.

## Affirmative Action

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, which include 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.

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

*More information about the Research Laboratory of Electronics can be found at http://www.rle.mit.edu/.*