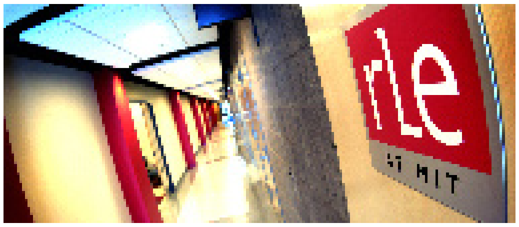
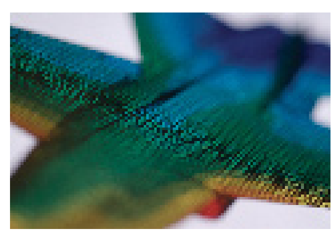
# Research Laboratory of Electronics




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, and Mathematics, the Biological Engineering Division, 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 (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 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 academic year 2004–2005 can be found in RLE Progress Report No. 147. The report is available online at http://www.rle.mit.edu/rleonline/ProgressReports/. What follows is a summary of research highlights from the past year.

## Circuits, Systems, Signals and Communications



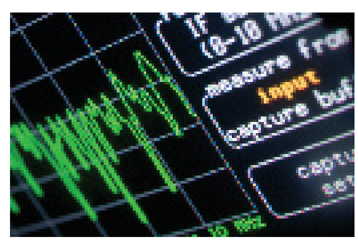
Professor Jacob White uses a range of engineering design applications to drive research in simulation and optimization algorithms and software. As part of the Singapore-MIT Alliance Program on Computational Engineering, Professor White and his collaborators have been developing design tools for bio-micromachined devices. Their recent work has included the development of efficient time integration techniques for cells in flow, techniques for extracting diffusion constants from measurements, and efficient techniques for extracting models from detailed simulations.

Professor Luca Daniel leads research that ranges from the development of highly efficient integral equation solvers for high-frequency integrated circuits and packages to the development of techniques for generating parameterized reduced-order models of analog components and subsystems. During the past year his field-solver research has led to a new algorithm for handling integrated circuits substrates in the context of interconnect extraction, and his new algorithm for model-order reduction has been successfully tested on several examples, including an industry-provided package network card.

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. One specific project is the use of video enhancement bits to permit video transmission at substantially higher resolutions than is currently allowed by the US HDTV standard, e.g., progressively-scanned video with a resolution in excess of 1,000 lines at 60 frames per second. Recent results from Professor Lim's group, which are quite encouraging, could serve as the basis for a future television standard.

The research of Professor Vivek Goyal and his students focuses on robust network communication and sampling at rates far below the Nyquist limit. Of particular interest has been the use of sparse signal models to establish connections between the preceding research topics. During the past year he has completed a thorough analysis of the ability to estimate a signal from noisy data based only on known sparsity with respect to a given waveform dictionary. Professor Goyal's work on sparse signal models could have applications ranging from multiple-access communications via wireless networks to assessing evolutionary oversampling in neurobiology.

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 signal processing in cell biology for improved modeling of cells and for the potential of new signal processing algorithms.




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 low-complexity capacity-approaching rateless codes for Gaussian channels. These permit reliable communication over channels whose signal-to-noise ratio is unknown. In other work, he has shown that a suitably designed temporal scheduler can dramatically reduce the multiplexing complexity needed to approach optimal throughput in multiple-antenna broadcasting.

Professor David Staelin and Dr. Philip Rosenkranz work on the development of instruments and algorithms for retrieving atmospheric and surface parameters from data collected by airborne or satellite sensors. Recent achievements include the successful matching of millimeter-wave radiances computed from numerical weather prediction models to observations simultaneously reported on National Oceanic and Atmospheric Administration operational weather satellites, and the mapping of global convective precipitation and its diurnal variations for consecutive years with ~500 km resolution.

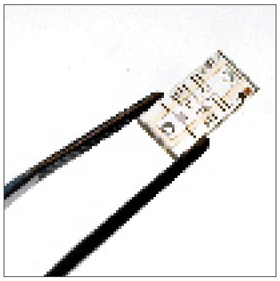
Professor Rahul Sarpeshkar is pursuing a collection of projects in biologically inspired electronics, including a low-power bionic ear processor, time-based hybrid computing, and analog VLSI vision systems. His fully implantable bionic ear processor for the deaf will enable 30-year operation on a 100 mAh battery with 1,000 wireless recharges. Its power consumption is 20 to 30 times lower than conventional cochlear-implant processors, which rely on analog-to-digital conversion followed by digital signal processing. For hybrid computation applications, he has developed an analog memory element, using a novel ultralow-leakage switch that cuts capacitor leakage to 10 aA in 1.5 μm technology and 0.66 aA in 0.5 μm technology. This represents a 15-fold to 160-fold improvement over prior implementations.

Professor Vladimir Stojanovic joined the MIT faculty—and RLE—in January 2005. His research interests 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. In initial work, he has shown that an approximately 40% improvement in on-chip data rate over long interconnects is possible—with the same complexity as previous techniques—by means of duo-binary signaling and on-chip equalization. He is currently working on a proof-of-principle test chip for this approach.

Professor Donald Troxel, in collaboration with Professor Carl Thompson of the Department of Materials Science and Engineering, is working on tools and techniques for system-level assessment of integrated circuit reliability, with a particular focus on electromigration and thermal effects. He has developed and released SYSREL, the first public domain tool for system-level interconnect reliability, which can treat both 2-D and 3-D circuit layouts as well as both copper and aluminium metallizations.

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. The immediate goal is to achieve chronic implantation in the Yucatan mini-pig. Development work during the past year resulted in the successfully design, fabrication, and testing of the stimulator microchip that is the heart of the implant.

This is the first year that Professor Elfar Adalsteinsson has been at MIT. His 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 sampling and spatial encoding of spectroscopic data, the estimation of brain metabolites in structurally identified tissue compartments, and the investigation of ferro-fluid nanoparticles as contrast and delivery agents in MRI.



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 microfluidic culture system that allows culturing of embryonic stem cells under different perfusion rates, thus providing unprecedented control of the cellular microenvironment. In other work, he has demonstrated a new spore concentrator that, for the first time, operates at high liquid flow rates and can deliver a concentrated sample for downstream processing.

Professor Dennis Freeman has been developing an interferometric-illumination technique that decouples the resolution of a light microscope from its working distance, depth of focus, and field of view. This approach dramatically increases the design space for optical microscopy, enabling high resolution to be obtained in combination with large working distance, depth of focus, and field of view. In particular, he has demonstrated the generation of a focused spot of light with sub-wavelength resolution by interfering a large number of unfocused laser beams, and he has shown how this principle can be used to obtain high-resolution fluorescence images without the use of high-numerical-aperture lenses.

This year's work in Professor Jongyoon Han's Nanofluidic BioMEMS group has focused on the development of novel nanofluidic devices for proteomic sample preparation. As part of this effort, his group demonstrated a nanofluidic protein pre-concentrator that is capable of million-fold protein concentration, as compared to the thousand-fold capability of currently available techniques. This enormous improvement in concentration power will lead to much more sensitive detection of biomarkers by acting as a "signal preamplifier" for proteomics, a field which is severely limited at present by the lack of an effective amplification strategy akin to polymerase chain reaction in genomics.

## Physical Sciences

Professors Daniel Kleppner and Thomas Greytak lead the Ultracold Hydrogen group, whose studies center on the structure of atomic hydrogen, ultracold collisions, the properties of hydrogen as a quantum gas, and ultrahigh precision spectroscopy. They have been pursuing an entirely new approach to cooling and trapping hydrogen that is based on buffer-gas loading. This technique has the advantage of enabling virtually any species to be loaded into a magnetic trap. As a result, evaporative cooling can be dramatically accelerated and its efficiency greatly increased by simultaneously confining both atomic lithium and hydrogen.

Professor Wolfgang Ketterle's research concentrates on the properties of Bose-Einstein condensates (BECs) and Fermi seas, the use of ultracold atoms for precision measurements, and the study of many-body physics through experiments with quantum degenerate gases. Together with Professor David Pritchard, he has had a string of major accomplishments this year: they demonstrated for the first time that the relative phase between two spatially separated BECs could be measured nondestructively by means of stimulated light scattering; they measured the systematic photon-recoil shift that is due to the refractive index of a dilute gas of atoms; and they observed vortices and superfluidity in a strongly interacting Fermi gas. BECs may lead to coherent-atom sources that could replace conventional atomic clocks in demanding applications such as atom interferometry, time and frequency standards, and direct-write lithography.

Professor Vladan Vuletic is interested in new methods for manipulating atoms in a regime wherein quantum-mechanical aspects dominate their behavior and properties. His group works with laser-cooled atoms and BECs to probe quantum states of matter, atom-photon interactions, and the interaction of condensates with surfaces. During the past year he has developed a high-efficiency source of single photons on demand. This source can be used for quantum key distribution, linear optics quantum computing, and long-distance quantum bit (qubit) teleportation.

Professor John Joannopoulos has been working on the development and application of a new method for the dynamical simulation of complex shock-wave dynamics in a molecular solid. Study of the propagation of shock waves in condensed matter has led to new discoveries ranging from new metastable states of carbon to the metallic conductivity of hydrogen on Jupiter. Until now, the standard approach to microscopic studies of shock-wave dynamics has been through non-equilibrium molecular dynamics (NEMD) simulations, whose computational load grows at least quadratically in the evolution time. His new multiscale molecular dynamics approach enables for the first time tractable calculations of shock phenomena over long durations that include chemical reactions. As an example, he investigated nitromethane experiencing shock compression at 300 K over a time span of many picoseconds. The results of this simulation—which would have required $10^5$ to $10^6$ times more computational effort with conventional NEMD—were especially exciting in that they explain several experimental observations of aci ion formation in highly pressurized and detonating nitromethane.

Professor Jin Kong's research on electromagnetics addresses a variety of problem areas, including left-handed metamaterials (LHMs), unexploded ordnance detection, multifunctional wideband radio-frequency systems, and synthetic-aperture radar interferometry. A key research highlight from the past year is his work on the retrieval and optimization of the constitutive parameters of bianisotropic metamaterials, with which he can now explain some hitherto unknown LHM phenomena. Because the mechanism for coupling the electric and magnetic fields in these man-made structures is now better understood, it can be used to design devices that have custom electromagnetic properties such as would be needed for novel antennas and low-observable structures.

Professor Abraham Bers is engaged in theoretical research on plasma electrodynamics and its applications. He has recently completed a study of current drive with electron Bernstein waves in toroidal magnetic-confinement plasmas. The results are of importance to controlled fusion-energy generation in general, and for the currently planned experiments on spherical tokamaks. In other work, his studies of intense laser-plasma interactions are relevant to energy generation via inertial-confinement fusion.

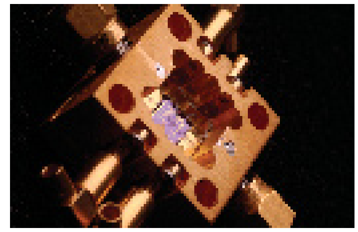
## Quantum Computation and Communication

Professor Seth Lloyd investigates methods for constructing quantum computers and quantum communication systems using atomic physics, quantum optics, and superconducting electronics, and collaborates with experimental groups—at MIT and elsewhere—in these areas. During the past year he has continued his investigation of the classical communication capacities of quantum channels in collaboration with Professor Jeffrey Shapiro, and has reported a proof-of-principle experiment for entanglement-assisted metrology in collaboration with Professor David Cory of the Department of Nuclear Science and Engineering.

Professor Isaac Chuang affiliated with RLE this year, having changed his faculty appointment from Media Arts and Sciences to Electrical Engineering and Computer Science. The research in Professor Chuang's group is aimed at harnessing the resources of quantum physics for novel information technology capabilities. During the past year they concentrated on developing new ways to prepare and control large numbers of quantum bits to realize machines to perform computations and quantum simulations beyond what can be done on classical computers. A particular achievement was the successful implementation of a new method for trapping and holding individual ions for long times that is compatible with planar semiconductor fabrication techniques. In addition to its relevance to quantum computation, this new planar ion trap may also be used to manipulate biological molecules.

Professor Jeffrey Shapiro and Dr. Franco Wong have 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 downconverters. These entanglement sources, when further developed, will be employed in an architecture for long-distance, high-fidelity qubit teleportation that they are instantiating, in collaboration with other researchers from MIT and Northwestern University. In other work, Dr. Wong has been using the two-photon hyperentanglement—momentum and polarization—produced by these downconverters to develop single-photon two-qubit (SPTQ) quantum logic. Unlike linear optics quantum computing (LOQC), which is based on the nonlinearity afforded by photodetection and is intrinsically probabilistic, SPTQ quantum logic is deterministic. On the other hand, LOQC is scalable, whereas SPTQ, in its current form, is not. Nevertheless, several applications of SPTQ quantum logic have been identified and work is continuing on solving the scalability problem.

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 perform the measurement process, to model the sources of decoherence, and to develop scalable 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 investigated the spectroscopy of these qubits using an ultrafast measurement scheme. Time-resolved experiments showed that the energy relaxation time between the macroscopic quantum states is about 10 μs. This long time macroscopic quantum coherence, together with the advanced fabrication techniques available, suggests the strong potential for realizing quantum computing with niobium-based superconducting qubits.

## 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 zone-plate-array lithography, which promises an affordable “dot-matrix” approach to nanolithography for rapid prototyping and small-volume manufacturing. An example of his opto-electronics research is the third-order add-drop filter based on optical ring resonators, which is an essential element in the 30 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.

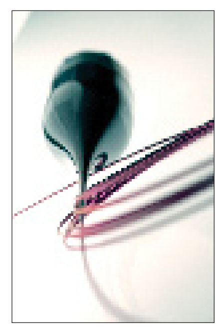
Professor Jing Kong joined the MIT faculty and RLE at the start of AY2005. She is interested in the fabrication and application of carbon nanotubes. Since her arrival, she has successfully built three chemical vapor deposition furnaces for the synthesis of single-walled carbon nanotubes, and set up a variety of characterization tools for studying nanotube materials and devices. One objective of her program is to improve chirality control in nanotube fabrication, as chirality plays a determining role in the electrical properties of the resulting nanotube.

Professor Karl Berggren’s Quantum Nanostructures and Nanofabrication group focuses on questions surrounding the application and fabrication of devices whose operation is based on the foundations of quantum mechanics. A key recent accomplishment from his group is the fabrication and demonstration of single-photon detectors using superconducting nanowires. These detectors have shown GHz counting rates, ~10% quantum efficiency, and extremely low dark-count rates. Efforts are now concentrated on increasing the detection efficiency. This technology will likely find applications in interplanetary optical communication, quantum key distribution, and linear optics quantum computing.

## Photonic Materials, Devices, and Systems

Professor Leslie Kolodziejski and Dr. Gale Petrich are working on the design and fabrication of photonic and opto-electronic devices in III-V compound semiconductors and in silicon. Their current research includes the development of an optical logic gate composed of semiconductor optical amplifiers that are monolithically integrated within a Mach-Zehnder interferometer, and the development of saturable Bragg reflectors for use in ultrashort-pulse lasers. A very exciting recent result from their work was demonstrating energy transfer of 1550 nm wavelength light within a super-collimator, i.e., a large area 2-D photonic crystal. The dispersion characteristics of such a structure confine the transverse dimension of a propagating light wave without requiring the usual refractive-index contrast needed to form a waveguide.

Professor Erich Ippen has continued his work on the generation and application of ultrashort optical pulses, and the study and development of high-index-contrast integrated photonic devices. Together with Professor Franz Kärtner, he has been exploring two novel materials—erbium-doped bismuth-oxide glass and nickel-doped zinc-alumino-silicate glass—as solid-state laser materials for the 1.55 μm wavelength band. The objective is to obtain a broader spectrum than existing sources, thus permitting a greater number of wavelength-division multiplexed channels in fiber-optic communications. His work on high-index-contrast integrated photonics—which includes collaboration with Professor Henry Smith on 3-D photonic crystals and integrated photonic add-drop filters—will facilitate direct integration of photonics and silicon electronics.



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. During the past year he reported the successful design, fabrication, and characterization of the first metal-insulator-semiconductor fibers. He also introduced a photodetecting fiber that detects light along its entire length, and wove a collection of these fibers into a grid structure that permitted provided $N^2$ pixels of spatial resolution with only $N$ photodetecting elements. In essence, Professor Fink has established a new paradigm for micro- and nanofabrication on kilometer-length scales, one which opens up exciting new opportunities for integrating electronic and optical functionalities into polymeric fiber and textile yarns.

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 constructed a low-jitter (27 fs, measured from 10 kHz to 20 MHz) laser for timing distribution in advanced accelerator and X-ray laser systems, and demonstrated sub-100 fs timing distribution at the MIT Bates Linear Accelerator Center. In collaboration with Professors Henry Smith and Erich Ippen, he made the first demonstration of an integrated, polarization-insensitive, high-index-contrast optical add-drop filter.

Professor James Fujimoto divides his research efforts between two areas: laser medicine 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 work, Professor Fujimoto and his collaborators have made significant advances in both the technology and medical applications of OCT. Specific achievements include development of real-time ultrahigh-resolution OCT based on a femtosecond fiber-laser continuum source and demonstration of its use for in vivo high-speed imaging of human skin; development of an adaptive wavelet filter for speckle reduction in OCT and demonstration of its use in ophthalmic OCT; and the first real-time in vivo imaging, with ~μm spatial resolution, of human cartilage in normal and osteoarthritic knee joints.

Professor Steven Johnson became a member of RLE this year, shortly after he joined the MIT faculty. His 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 upon one of the most widely used software libraries for fast Fourier transforms, "the fastest Fourier transform in the West". One of his recent accomplishments was to show that by controlling the spacing between a pair of omnidirectional multilayer mirrors that are guiding a light beam one can achieve an optically actuated micromechanical device. In another project, he has found important, counter-intuitive behavior of the roughness-induced scattering losses in photonic crystal structures that indicates such crystals can actually reduce losses in on-chip waveguides.

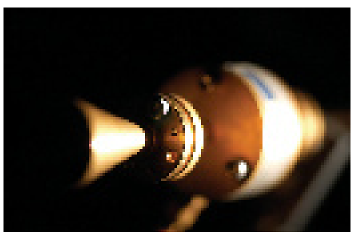
Professor Marin Soljacic, who had previously been a principal research scientist in RLE, joined the Physics Department faculty this summer. His research seeks to develop nanophotonics, the technology by which light may be manipulated at nanoscales in time, space, and energy. During the past year he has described a system—involving electromagnetically induced transparency in a photonic crystal microcavity—in which one should be able to observe optical nonlinearities down to single-photon energy levels. He has also described a class of systems—involving surface plasmons in multilayer structures—which, for the first time, enable observation of slow-light phenomena with no limit on the frequency bandwidth. These concepts should have important applications for 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. During the past year he demonstrated that the maximum efficiency of polymeric light-emitting devices is only 25%. He also developed a model to explain the current-voltage characteristics of organic electronic devices, which will be relevant to the design of organic light emitters, solar cells, and organic transistors.

Professor Vladimir Bulovic's laboratory is addressing a wide variety of topics related to hybrid organic/inorganic optical and electronic devices. Recent achievements include a microcontact printing process to generate quantum-dot light-emitting diodes (QD-LEDs) with features as small as 25 μm and printed QD patterns as small as 150 nm, a theoretical framework for the diffusion dynamics of excitons in disordered molecular organic solids, the first electrically pumped exciton-polariton light-emitting devices, and organic light-emitting devices capable of acting as memory cells.

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 continued their development of a system for performing multiple microbial growth experiments in parallel, so as to facilitate both bioprocess development and fundamental studies of the dynamic response of microbes to changing conditions. They have also completed the design of an integrated optical isolator that provides at least 12 dB of isolation for both electromagnetic polarizations, in a device that is only ~700 μm long. In other work, they have developed a thermoreflectance microscope with 10 mK temperature resolution, and demonstrated its ability to map the optical power flows in semiconductor optical amplifiers. This technology holds considerable promise for wafer-scale testing of photonic integrated circuits.

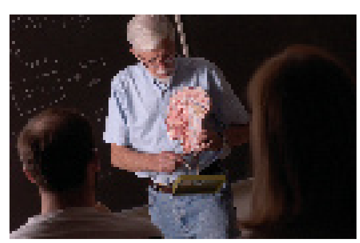
Professor Qing Hu's research is focused on the development of terahertz (THz) lasers and electronics. His THz quantum cascade lasers have achieved world-record performance in many respects: the highest operating temperature in the pulsed mode (164 K); the highest operating temperature in continuous-wave mode (117 K); and the longest wavelength (141 μm). These sources will be of great importance in opening up the THz spectral region for remote sensing, imaging, communications, and ultrafast signal processing.



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. Several years ago he discovered a new physical effect that provided a five-fold to eight-fold increase in the efficiency of thermal-to-electrical conversion in a bulk semiconductor by adding a thin emitter layer on the surface. During the past year he has continued to refine his model for this device concept, and, in collaboration with researchers doing experiments at Eneco, has been working toward development of a viable commercial technology.

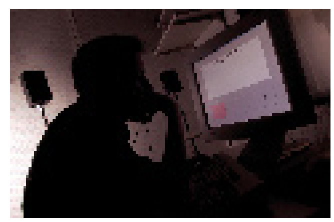
### Communication Biophysics

Professor Kenneth Stevens leads a research group whose goal is to develop principles that explain how human speakers and listeners of all ages can communicate effectively, despite large variations in the acoustic properties of words. These principles involve a balance between minimization of effort for the speaker, and introduction of enhancements to increase perceptual saliency for the listener. 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 study of normal and deviant speech development in children.



Professor Louis Braida and Dr. Julie Greenberg have as their long-term research goal the development of improved hearing aids and cochlear implants. Specific goals for their 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. One of their recent results is the identification of a novel metric that is well suited to predicting the intelligibility of speech that has been subjected to a number of linear or nonlinear distortions. This metric will be used to evaluate promising noise-reduction strategies for cochlear implant processing.

Dr. Charlotte Reed's research has as its long-term goal 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 extended her basic studies of human touch through a series of experiments examining discrimination of temporal onset-order. She has also worked on tactual displays of consonant voicing as a supplement to lip-reading, and of environmental sounds, to provide environmental awareness to deaf individuals.



Dr. Andrew Oxenham is addressing a collection of topics in auditory perception and cognition. These include performing computational modeling of inner ear processing, using acoustic simulations to understand the fundamental limits of the stimulators currently used in cochlear implants, and using a combination of behavioral and neuroimaging techniques to study how the brain organizes the acoustic input into different perceptual "objects" and "streams". Recently, he used acoustic stimuli that can be perceived in two ways—as one stream of alternating tones or as two separate streams of repeating tones—to make the first demonstration that changes in neural response may be correlated with changes in perception that are independent of physical stimulus changes. This result opens a new window through which to view the neural activity underlying how we perceive the world.

Dr. Bertrand Delgutte's research interest is the neural mechanisms that mediate the ability of normal-hearing people to process speech and other sounds of interest in the presence of competing sounds, and how these mechanisms are degraded in the hearing impaired. His recent work includes: investigating the spatio-temporal representation of the pitch of harmonic complex tones in the auditory nerve; and predicting lateralization performance at high frequencies from auditory-nerve spike timing.

Dr. Donald Eddington heads the Cochlear Implant Laboratory at the Massachusetts Eye and Ear Infirmary. His research objective is to identify the best stimulus configurations for effectively delivering binaural information with bilateral cochlear implants. To do so he employs closely integrated neurophysiological, psychophysical, and theoretical studies. His work, during the past year, has focused on measuring sensitivity to interaural time difference of bilaterally implanted human subjects.

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 recent experiment in which a modified first-formant frequency was fed back to subjects as they pronounced simple utterances showed varying amounts of compensation for this shift that were related to the subjects' auditory acuities. This result is consistent with a neurocomputational model of speech motor planning that has been developed by one of his research collaborators.

Professor Dennis Freeman made further advances in his work investigating the way the inner ear processes sound. During the past year he developed a new technique for imaging and measuring motion of structures in the inner ear. The technique combines the imaging capabilities of optical coherence microscopy with the motion measurement capabilities of heterodyne laser-Doppler velocimetry. He expects that this new method will allow sound-induced motion measurements to be made on all structures in the inner ear, thus providing key data for understanding the mechanisms that underlie the extraordinary sensitivity of hearing.

### 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. Fred 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 second CIPS annual meeting, which was held in May 2005, attracted representatives from more than 30 photonics companies and featured plenary talks by Dr. Robert Leheny (deputy director of the Defense Advanced Research Projects Agency), Dr. Stan Lumish (chief technical officer of JDS Uniphase), and Professor Eli Yablonovitch (UCLA).

## Appointments, Awards, and Events

Dr. Elfar Adalsteinsson was appointed assistant professor of electrical engineering and computer science and health sciences and technology, and, effective 1 July 2005, will be appointed the Robert J. Shillman assistant professor of electrical engineering and computer science and health sciences and technology.

Dr. Steven G. Johnson was appointed assistant professor of applied mathematics.

Dr. Jing Kong was appointed assistant professor of electrical engineering and computer science.

Dr. Marin Soljacic will be appointed assistant professor of physics, effective 1 July 2005.

Dr. Vladimir M. Stojanovic was appointed assistant professor of electrical engineering and computer science.

Professor Isaac L. Chuang was appointed associate professor of electrical engineering and computer science, and, effective 1 July 2005, will receive tenure.

Professor Yoel Fink will be promoted to Thomas B. King associate professor of materials science and engineering, effective 1 July 2005.

Professor Anantha P. Chandrakasan will be appointed the Joseph F. and Nancy P. Keithley professor of electrical engineering, effective 1 July 2005.

Professor Jacob K. White was appointed the Cecil H. Green professor of electrical engineering and computer science.

Professor Marc A. Baldo was appointed the Esther and Harold E. Edgerton assistant professor of electrical engineering.

Professor Joel Voldman was appointed NBX assistant professor of electrical engineering.

Mr. David W. Foss was appointed assistant director for information technology services.

Ms. Krista L. Van Guilder was promoted to senior media and design specialist.

Ms. Melanie A. Straight was appointed assistant fiscal officer.

Mr. Sukru Cinar was appointed networking and systems specialist.

Professor Daniel Kleppner received the 2005 Wolf Prize in Physics.

Professor James G. Fujimoto was made a fellow of the American Association for the Advancement of Science.

Professor Marin Soljacic received the 2005 Adolph Lomb Medal from the Optical Society of America.

Professor Wolfgang Ketterle delivered the 33rd James R. Killian Jr. Faculty Achievement Award lecture.

Dr. Herwig Kogelnik of Lucent Technologies presented the First Hermann Anton Haus lecture.

The APS Study Group on Boost-Phase Intercept Systems for National Missile Defense—chaired by Professor Daniel Kleppner—received the 2005 Leo Szilard Lectureship Award from the American Physical Society.

Professor Vladimir Bulovic received a Presidential Early Career Award for Scientists and Engineers from the National Science Foundation, and was named by *Technology Review* to its TR100 list of top innovators under the age of 35.

Professor Dennis M. Freeman received the 2005 Bose Award for Teaching Excellence.

Professor Rahul Sarpehskar received a 2005 Ruth and Joel Spira Award for Teaching Excellence.

Professor Vladan Vuletic received the 2005 Undergraduate Research Opportunities Program Faculty Mentor of the Year Award.

Mr. Cort N. Johnson, Mr. Thomas A. Pasquini, and Ms. Kendra M.D. Vant were co-recipients of the 2005 Carol Costa Award.

Mr. Nitzan Gadish was name a Siebel scholar.

Mr. Harry Lee and his Balico team were winners of the 2005 MIT $50K Entrepreneurship Competition.

Mr. Ying-Chih Wang received the 2005 Helen Carr Peake Research Prize.

Ms. Dorothy A. Fleischer, Ms. Donna L. Gale, Mr. William R. Gibbs, and Ms. Tricia D. Mulcahy received 2005 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: (1) maintaining our high standards for recruitment procedures that include sending job postings to minority colleges and organizations; (2) 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 (3) being committed to finding new techniques to identify more effectively women and minority candidates. During the past year a woman was hired as a research scientist, a woman was appointed assistant fiscal officer, and a woman was promoted to senior media and design specialist.

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

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