George R. Harrison Spectroscopy Laboratory

The George Russell Harrison Spectroscopy Laboratory conducts research in modern optics and spectroscopy to further fundamental knowledge of atoms and molecules and explore advanced engineering and biomedical applications. Professor Michael S. Feld is director; professor Robert W. Field and Dr. Ramachandra R. Dasari are associate directors. As an interdepartmental laboratory, the Spectroscopy Laboratory encourages participation and collaboration among researchers in various disciplines of science and engineering. A special relationship has developed with the Department of Chemistry, which now administers personnel and fiscal matters. Core investigators include Professors Field and Moungi G. Bawendi, Keith A. Nelson, and Andrei Tokmakoff (Chemistry Department), Feld (Physics Department), William H. Green (Chemical Engineering Department), Mildred Dresselhaus and Jing Kong (Electrical Engineering and Computer Science Department), and Dr. Dasari.

The laboratory operates a resource facility, the MIT Laser Biomedical Research Center, a biomedical technology resource of the National Institutes of Health, the goal of which is to develop basic scientific understanding and technology for advanced biomedical applications of lasers, light, and spectroscopy; core, collaborative, and outside research is conducted there. The MIT Laser Research Facility provides resources for core research programs in the physical sciences for core faculty members.

On Saturday, June 27, 100 friends and colleagues of Professor Feld gathered for "Feld Fest," to celebrate his achievements in physics and in biomedical research, his 50 years at MIT, and his 33 years as director of the Spectroscopy Laboratory. Former students and postdocs traveled from around the world for the all-day celebration, which included a program of scientific talks and a banquet. The talks examined the breadth of Feld's research, which has ranged from fundamental physics—superradiance and innovations in laser spectroscopy—to biomedicine and biomedical engineering, new kinds of microscopy, spectroscopic identification of cancer cells, and novel uses of the electric field to study cell behavior.

Research Highlights

Professor Field, in collaboration with professor Anthony Merer (University of British Columbia and Academia Sinica), has characterized the vibrational levels of the acetylene S1 state up to the top of the *trans*↔*cis* isomerization barrier, with the goal of finding "local-bender-pluck" states from which the S0 state acetylene↔vinylidene isomerization region can be accessed. Several of these vibrational levels are previously unobserved *cis*-bent conformers. A factor of 1,000 improvement over standard mm-wave spectroscopy has been achieved by the MIT chirped-pulse millimeter-wave (CPmmW) spectrometer to pure electronic transitions in Rydberg states and in identifying extremely large amplitude motion eigenstates among the mostly "ergodic" highly excited vibrational levels of small polyatomic molecules. A slit-jet system being assembled by Dr. Kirill Kuyanov will increase the sensitivity of the CPmmW scheme by an additional factor of 1,000.

Professor Bawendi and Dr. August Dorn demonstrated nanowire growth between two electrodes controlled by an applied voltage. Professor Bawendi used a photoluminescence up-conversion apparatus to study enhanced carrier multiplication in PbS and PbSe nanocrystals and concluded that most of the research described in the literature on the subject was likely to be contaminated by extraneous signals. Dr. Andrew Greytak, with Professors Bawendi and Daniel Nocera of the Chemistry Department, continued to develop novel fluorescent chemical sensors based on energy transfer, with a focus on the development of nanocrystalline fluorescence resonant energy transfer (FRET) probes suitable for pH imaging in biological microenvironments. Professors Bawendi, Vladimir Bulovic, and Marc Kastner of the Physics Department continued their studies of close-packed quantum dot films in light-emitting and photodetecting devices. Professor Bawendi and his students demonstrated a method to measure fast (<1 μsec) dynamics at the single-molecule scale with quantum dots and are now applying this technique to biological systems.

Professor Tokmakoff has investigated the dynamics of proton transfer in aqueous solution and developed two-dimensional infrared (2D IR) spectroscopy as an assay of protein secondary structure. Femtosecond 2D IR spectroscopy characterized the process of hydroxide ion transport in water through proton transfer from hydrogen-bonded water molecules to the hydroxide ion. Multimode 2D IR spectroscopy of the amide I and amide II vibrations of the protein backbone was also used to correlate their vibrational frequency shifts, providing a way of quantifying secondary protein structure.

Professor Nelson used optical methods to generate and measure longitudinal and shear acoustic waves covering nearly every frequency and wavelength range that can be supported in condensed matter. The acoustic properties of glass-forming liquids were measured at various sample temperatures to assess complex structural relaxation dynamics, including the previously inaccessible transition between relatively fast and slow relaxation events. The results allowed direct testing of recent theoretical models of the liquid–glass transition, which continues to elude fundamental understanding. The techniques have also allowed measurement of acoustic and nanoscale heat transport properties of thermoelectric superlattice materials. In addition, the Spectroscopy Laboratory's Outreach Laboratory provided opportunities for high school students to make photoacoustic measurements on thin films and learn about advanced materials and modern optics.

Professor William Green was appointed editor of the *International Journal of Chemical Kinetics*. He and several of his students received the American Chemical Society's Glenn Award for the best paper presented in fuel chemistry. The prize-winning paper reported their measurements of the kinetics of reactive intermediates important in combustion, using one of the laboratory's advanced laser systems.

Professors Dresselhaus and Kong used resonant Raman spectroscopy to characterize nanocarbon materials, including single- and double-walled carbon nanotubes (SWNTs and DWNTs) and graphene. During this past year the Kong-Dresselhaus group focused on studies of the Kohn anomaly in metallic carbon nanotubes using an electrochemical gate to vary the Fermi level. Another project studied the resonant Raman effect from both the inner and outer tubes of DWNTs at the single DWNT level, exploring differences in the spectra for DWNT for which the inner tubes were semiconducting and the outer tubes were metallic, and vice versa. Another project involved study of the resonance window for the radial breathing mode for semiconducting and metallic tubes within single 2n+m families. The remaining topic involved the use of Raman spectroscopy to study interlayer stacking in graphene prepared by mechanical exfoliation and chemical vapor deposition–based growth processes, with the objective of optimizing the growth process.

Professor Feld and Drs. Dasari, Wonshik Choi, Dan Fu, Niyom Lue, Gajendra Singh, Zahid Yaqoob, and Chung-Chieh Yu of MIT; Kamran Badizadegan of MIT and Massachusetts General Hospital; and Drs. Maryann Fitzmaurice of University Hospitals, Cleveland; Gregory Grillone and Elizabeth Stier of Boston Medical Center; and Arnold Miller of MetroWest Hospital conducted basic and clinical spectroscopic biomedical studies. Dr. Choi and Professor Feld continued to develop refractive index tomography that produces three-dimensional video-rate images of refractive index in living biological cells. Using this technique, Dr. Choi and Professors Feld and George Benedek of the Physics Department studied the structure of newly discovered cholesterol helices on the 10-nm scale. Dr. Choi and Professors Feld and Subra Suresh of the Department of Materials Science and Engineering studied cell membrane fluctuations to assess the mechanical properties of malaria-infected red blood cells and demonstrated that disease status can be determined from mechanical properties and hemoglobin concentration. Dr. Choi and Professors Feld and Kenneth Anderson of the Dana-Farber Cancer Institute have studied the use of refractive index as a marker for detecting myeloma cells. Drs. Choi and Fu and Professor Feld have developed a UV refractive index tomographic system to image DNA in living cells. Dr. Yaqoob and Professors Feld and H. Sebastian Seung of the Department of Brain and Cognitive Sciences and the Physics Department continued to study cell electromotility, the subnanometer motions of live cells induced by oscillatory electrical stimulation. Dr. Yaqoob and Professor Feld developed a new technique that can simultaneously observe cell membrane motion at multiple sites with picometer sensitivity. Drs. Badizadegan, Miller, and Fitzmaurice and Professor Feld continued clinical studies using multimodal spectroscopy—the combination of Raman, fluorescence, and reflectance spectroscopy—to identify vulnerable plaques in the artery and diagnose cancer lesions in the breast. Recently, Dr. Fitzmaurice and Professor Feld developed a new side-viewing probe to collect spectra from patients during breast needle biopsy. Drs. Badizadegan, Grillone, and Stier and Professor Feld employed quantitative spectroscopy—the combination of fluorescence and reflectance spectroscopy—to diagnose precancer in the oral cavity and the uterine cervix. Drs. Choi and Yu and Professor Feld also characterized subcellular morphology with both intensity- and field-based light-scattering spectroscopy.

Michael S. Feld
Director

Additional information about the Spectroscopy Laboratory can be found at http://web.mit.edu/spectroscopy/.