RESEARCH LABORATORY OF ELECTRONICS year ended June 30, 2024, Vice President for Research

The Research Laboratory of Electronics at MIT (www.rle.mit.edu) is a vibrant intellectual community and one of the Institute's earliest interdepartmental academic research centers. The mission of RLE is the furthering of scientific understanding and leading innovation to provide service to society. RLE research spans basic science and engineering across an extensive range of natural and man-made phenomena. RLE harnesses expertise in fields as diverse as quantum physics, information theory, synthetic biology, and power electronics. We synthesize these disciplines for the benefit of applications in communication systems, energy transduction, computation, and innovations in diagnostics and treatment of human diseases.

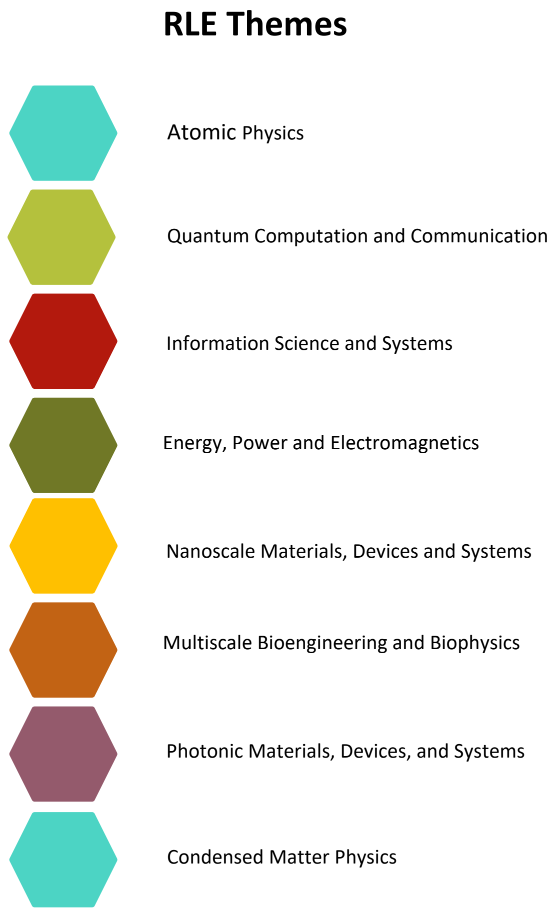

Fig. 1. RLE's eight major themes.

RLE was founded in 1946 following the ground-breaking research that led to the development of Ultra High-Frequency Radar, a technology that changed the course of World War II. It has been home to some of the great discoveries made in the 20th century at MIT. Cognizant of RLE's rich history and focus on maintaining a position as MIT's leading interdisciplinary research organization, RLE fosters a stimulating and supportive environment for innovative research and impact.

With a research volume of $67.4 million in fiscal year 2024, the Lab manages more than 250 active research projects and services for 98 principal investigators including 338 graduate students and 105 undergraduates. This year we were joined by Assistant Prof. Suraj Cheema from DMSE and EECS, as well as members of the Condensed Matter Group from Physics.

Since 2011, the Lab has been endowed by royalties from HDTV intellectual property developed by lab researchers. This endowment is the basis for RLE's discretionary activities and budget. Major research funding is provided by Department of Defense (DoD) agencies, the National Science Foundation (NSF), the National Institutes of Health (NIH), the Department of Energy (DoE), and the National Aeronautics and Space Administration (NASA). Other projects are funded through industry and private foundations.

RLE LABORATORIES AND RESEARCH HIGHLIGHTS

The 2023-2024 academic year saw many awards, recognitions and milestones for RLE investigators. The following is a summary:

ATOMIC PHYSICS

The research of **Professor Vladan Vuletic** focuses on quantum measurements, quantum computing, and other quantum technologies. In particular, he studies how to use quantum mechanical correlations (entanglement) to improve atomic clocks and atomic interferometers and to enable quantum computation. Recent highlights include the demonstration of high-quality quantum gates in a neutral-atom quantum computer, as well as the first demonstration of quantum error correction and circuits with error-corrected quantum bits. Vuletic and his group also demonstrated an effective evolution backward in time that enables us to overcome limits in measurement precision in quantum sensors. Vuletic is co-founder of a Boston-based quantum computing startup company, Quera, with over 70 employees.

Ultracold Quantum Gases Group under the direction of **Professor Martin Zwierlein** in experimental atomic physics, uses atomic and molecular gases at ultralow temperature to realize novel states of matter and to perform quantum simulations of condensed matter and nuclear physics problems.

A highlight was the joint work with **Assistant Professor Richard Fletcher** and The Fletcher lab, whose research investigates the quantum behavior of many-particle systems using dilute cooled atomic vapors, focuses on the observation of chiral edge transport in a rapidly rotating Bose gas, recently published in Nature Physics. The frictionless, directional propagation of particles at the boundary of topological materials is one of the most striking phenomena in transport. These chiral edge modes lie at the heart of the integer and fractional quantum Hall effects, and their extraordinary robustness against noise and disorder reflects the quantization of Hall conductivity in these systems. Despite their vital importance, controllable injection of edge modes, and direct imaging of their propagation, structure, and dynamics, are challenging. In this work, they were able to demonstrate the distillation of individual chiral edge states in a rapidly rotating bosonic superfluid confined by an optical boundary.

On the Fermi gas microscope, the Zwierlein group is currently investigating the fate of fermion pairing in the presence of spin imbalance, when not every spin-down fermion can find a spin-up partner to pair with. These investigations will shed light on the competition between superconductivity and magnetism, in regimes where new states of matter are predicted to resolve this tension in elegant ways.

ENERGY, POWER AND ELECTROMAGNETICS

Assistant Professor Yufeng (Kevin) Chen's research focuses on developing agile and autonomous insect-scale aerial robots powered by muscle-like soft actuators. During the past academic year, the team has developed a new robot platform for exploring sensing, computation, and power autonomy. The team has shown 2 major results in the past 12 months. First, the redesigned robot shows substantial improvement in payload, flight precision, and endurance compared to existing aerial robots at the same scale. The work shows 100 times improvement in flight time and better agility than aerial insects, and it has been accepted by the journal *Science Robotics*. Second, the team has explored high-voltage generation by designing triboelectric nanogenerators. The work is published in the journal *Nano Energy*. The new robot platform, along with exploration in high voltage energy sources, opens opportunities towards achieving autonomous flights critical for potential applications such as assisted pollination and environmental exploration. The soft artificial muscles developed from this research have shown promise in other applications, such as wearable haptics, microfluidic actuators, and actuators for legged robotic systems.

Assistant Professor Samantha Coday's research group focuses on the analysis, design, and optimization of power converters for future electrification. Her group has demonstrated a novel capacitor-based topology, with high efficiency and power density, which unlocks the wide range conversion required for battery integration in more electric aircraft. Her group has also made advancements in topologies for wireless power transfer, with applications in biomedical device charging and electric vehicles. They have also made progress in ultra-dense power converters with applications in capacitive-based isolation and intermediate conversion in electric vehicle drivetrain. Finally, her research group has worked on practical challenges of implementing capacitive-based power conversion such as start-up and control.

The focus of **Principal Research Engineer, Chathan Cooke's** research was in two main areas: (1) optimization of multivariable physical systems and (2) energetic electron/photon beam interactions with materials. Enhanced modeling with genetic algorithm optimizations was used to establish new high-efficiency resonant power transformer designs with experimental confirmation of performance. Energetic electron and photon beams were used for improved durability materials for hip and knee implants, and the development of satellite solar flux detectors. Both projects apply basic physics and modeling to yield improved practical devices for worldwide application in high-efficiency power systems, medical devices, and the impact of solar events.

Post-Tenure Professor James Kirtley of the Laboratory for Electromagnetic and Electronic Systems (LEES) is a specialist in electric machinery and electric power systems. Professor Kirtley is following a project in the Gas Turbine Laboratory led by Professors Zoltan Spakovszky and Edward Greitzer to develop a 1 MW Motor-Generator set to serve as a prototype for aircraft propulsion machines. That project is working out issues relating to balancing and mechanical vibrations and soon will be entering electrical testing. During the reporting year, they finished a project in Lithium cells that was sponsored by the Office of Naval Research. The work included the characterization of cells, involving the building of simulation models and the development of cell balancing mechanisms.

Professor Jeffrey Lang's research studies electromagnetic and electromechanical energy conversion, motion control, and sensing systems. Applications range from micro/nano-scale electromechanical actuators and sensors to megawatt-scale machines. As an acoustics example, together with Massachusetts Eye and Ear, and Columbia University, they continue to develop a fully implantable inner-ear microphone and amplifier system for assistive hearing devices. The system enables hearing 24/7 including during sleep, comfort during physical activities, and acoustic enhancement through the external ear for improved hearing and localization, among other significant benefits. Last year they demonstrated through multiple cadaveric experiments that the system exhibits a sound quality, sensitivity, and noise floor comparable to commercial hearing aids independent of human anatomy. They further demonstrated that the system is insensitive to everyday electromagnetic interference. A second example concerns the development of piezoelectric resonators as energy storage elements in power electronic circuits, research conducted in collaboration with **Professor David Perreault** of EECS. As the size of the circuits is miniaturized, for example, to permit board-scale or chip-scale integration, the group has shown that the power handling capacity of such resonators exceeds that of traditional inductor-capacitor resonators. This enables power electronic circuits to have much higher power density. To support the development of the resonators, they experimentally mapped the power handling capabilities of various piezoelectric materials, enabling circuit optimization and a more realistic assessment of circuit performance.

Professor Steven Leeb is also a part of the Grainger Energy Machines (GEM) facility at MIT. His group, the Electromechanical Systems Group (ESG), harnesses energy conversion processes. They had an extraordinary year developing systems for controlling and generating energy, with several highlights. One example: Professor Leeb and his group were awarded US Patent 11,888,548 in January 2024, disclosing a new technique for creating self-organizing loads in power systems. This patent discloses techniques for using existing power lines as communication and control interconnections for HVAC systems that become "aware" of the operation of neighboring HVAC systems. This is analogous to the way a good driver is aware of neighboring cars while driving. Using this new information, a "self-driving" HVAC system maintains occupant comfort by consuming electric energy on a schedule interleaved with the operation of neighboring units in other buildings. This approach shaves peak electrical demand and opens the door to a new market for "self-driving" appliances that respond to utility demand control signals, all while providing good service and transparent operation to facilities and occupants.

Professor David Trumper's research focuses on precision mechatronics applied to problems from health care and bioengineering to precision machine tools and semiconductor manufacturing. His group is currently pursuing new approaches in two main areas: (1) very high acceleration motion systems for semiconductor manufacturing, with an emphasis on the core elements of semiconductor chip printing equipment, and 2) in collaboration with Professor Linda Griffith in MIT's Department of Biological Engineering, designing mechatronic solutions for novel multi-organ human tissue bioreactors creating new micro-physiological systems for the in vitro study of human organ tissues. In the semiconductor projects, his group has invented new mechanisms and control approaches for mechanically and electromagnetically driving very high acceleration motion of magnetically levitated positioners carrying the master patterns for chip printing. In the bioengineering projects with Prof. Griffith, his group has created new types of pumps, valves, and pressure regulators configured on new designs of tissue culture platforms. These platforms are intended to be manufactured in quantity and allow culturing of human organ tissues such as the gut, brain, liver, and endometrium in ways that allow the tissues to exhibit behaviors like those in the body. The driving goal is to enable studying human organ tissues and important associated behaviors such as immune response and microbiome interactions. This will enable studying disease processes and treatments for conditions such as diabetes, endometriosis and Lyme disease.

INFORMATION SCIENCE AND SYSTEMS

Professor Vincent W S Chan's group research focuses on a new disruptive architecture of heterogeneous satellite networks from Physical to Application Layers. A research and development plan and proposal were developed for an ultra-wideband radio frequency (RF)-based software-defined radio (SDR) solution ranging from 10-30 GHz (Ku/Ka) in the form of a flat panel modular phased array antenna system. This all-in-one platform is aimed for satellite communications on the move (SATCOM-on-the-move) future digital beamforming radars while being flexible to accommodate technical challenges such as atmospheric, turbulence-induced uncertainties, and degradations. Professor Chan will serve as a co-PI and the co-architect of the five-year program (approved for $5M funding by a Korean government new initiative for the next three years). In a parallel research effort, they have assembled a team of high-level network leaders from the US industry and government to explore the frontiers of network research necessary to enable integrated heterogeneous networks of the future. The desired outcome is a new network architecture construct that interconnects multiple disparate communication and network modalities (fiber, wireless, open-air RF, and satellites) that is scalable, highly controllable, resilient, secure, and self-adapting to traffic conditions and application requirements. These inputs will be used to help US funding agencies decide on specific research funding in the network area this coming year.

Professor Anantha P. Chandrakasan's Energy-Efficient Circuits and Systems Group focuses on hardware security, life science and health applications, and low-power edge computing. While the group's research yielded many successful outcomes this year, here are two highlights related to secure circuits and systems for artificial intelligence. First, they developed a design space exploration framework for secure deep neural network accelerators supporting trusted execution environments [1]. This framework enables systematic evaluation of diverse custom accelerators and cryptographic hardware designs for their performance, area, and energy. This framework also optimizes the compute and data movement in secure accelerators, providing up to 33% speedup and 50% better energy-delay product than the previous optimization algorithm. This work can enhance the privacy and integrity of artificial intelligence from the hardware level and help identify the optimal secure designs. Second, a design for security against hardware eavesdropping attacks is proposed for digital in-memory compute accelerators [2]. Computation operations are protected using a logic type that has power consumption uncorrelated to the model and inputs, and a lightweight cipher is integrated with the model transfer operations such that the weights are only present in encrypted form off-chip. Through an optimized implementation of these contributions, they presented a system for secure machine learning accelerated in hardware that is applicable for privacy and integrity in a variety of applications including augmented/virtual reality, health monitoring, and speech processing.

> [1] K. Lee, M. Yan, J. S. Emer and A. P. Chandrakasan, "SecureLoop: Design Space Exploration of Secure DNN Accelerators," *2023 56th IEEE/ACM International Symposium on Microarchitecture (MICRO)*, Toronto, ON, Canada, 2023, pp. 194-208.
> [2] M. Ashok, S. Maji, X. Zhang, J. Cohn and A. P. Chandrakasan, "A Secure Digital In-Memory Compute (IMC) Macro with Protections for Side-Channel and Bus Probing Attacks," *2024 IEEE Custom Integrated Circuits Conference (CICC)*, Denver, CO, USA, 2024, pp. 1-2, DOI: 10.1109/CICC60959.2024.10529033.

Professor Jae Lim's group is involved in the development of image and video processing methods. During the last year, they studied a pragmatic solution to the problem of establishing eye contact in video conferencing applications. By utilizing two or more cameras, they demonstrated that 2-dimensional video processing can lead to a good solution without the computational burden of 3-dimensional modeling. In another project, they began working on a gesture-based page-turner for those musicians who use electronic music scores on an iPad or an Android tablet. They plan to continue working on this project.

The Atomic Architects, led by **Assistant Professor Tess Smidt**, made significant advances in symmetry-preserving machine learning models in 2024. Building on the success of Equiformer, an equivariant transformer neural network used to predict quantum mechanically accurate forces for molecules and materials (International Conference of Learning Representations (ICLR 2023)), they introduced EquiformerV2 (ICLR 2024), incorporating attention re-normalization and spherical activation functions. This model set new benchmarks for quantum-mechanically accurate predictions in large-scale molecular dynamics and catalysis.

In parallel, their Ophiuchus model, a hierarchical coarse-graining autoencoder for learning compressed representations of 3d protein structures (GEM 2024, a workshop at ICLR (https://www.gembio.ai/)), a hierarchical autoencoder, achieved lossless encoding and realistic generation of protein conformations. Ophiuchus paves the way for applying these techniques to broader atomic systems, enhancing our ability to understand and design complex molecular structures.

Symphony, an autoregressive generative model for molecules (ICLR 2024), addresses the challenge of generating molecules while preserving permutation symmetry. Utilizing equivariant spherical harmonics, Symphony outperforms previous models in generating 3D molecular structures and shows promise for the efficient generation of larger systems.

Their exploration of symmetry-breaking techniques introduced relaxed group convolutions (International Conference on Machine Learning (ICML 2024), enabling their models to handle asymmetric environments and spontaneous symmetry breaking, applicable to phenomena like phase transitions and turbulence.

Associate Professor Vivienne Sze works on energy-efficient computing systems for autonomous navigation, digital health, and embedded devices. Key advances include: 1) With Sertac Karaman, we developed a memory-efficient method called GMMap to build a 3D map of the environment that can be used for autonomous navigation. 2). Compute-in-memory (CiM) accelerators can reduce data movement for AI tasks. With Joel Emer, they developed an open-source tool called CiMLoop to model diverse CiM systems and explore decisions across the CiM stack. **(**1) Machine learning for scientific and engineering applications. Here they developed a new nested low-rank approximation methodology for efficiently computing very high-dimensional singular value decompositions for diverse applications, examples of which include analysis of atomic eigenstates and energies, complex statistical model building from data, and the design of cross-domain retrieval systems such as sketch-based image retrieval; (2) Machine learning methods for signal separation. Here they developed powerful diffusion models and score-based methods for data-driven signal separation in diverse applications. More generally their architectures yield state-of-the-art performance in key application domains, including communication settings involving RF interference cancellation. Moreover, they served as the reference designs for recent grand challenges in the field for the broader community; (3) Methods uncertainty quantification in machine learning. Here they have developed new scalable methods for the calibration of large language models, so that they can produce accurate estimates of the confidence of their predictions. Their methodology, termed thermometer, employs a compact auxiliary model and is effective on diverse tasks. The architecture was featured in a recent MIT News article.

Professor Lizhong Zheng developed the fundamental theory to help machine learning algorithms to be applied to engineering problems. In the current development of machine learning and artificial intelligence, a major obstacle is the lack of interpretability of the complex neural network models trained with large datasets, and consequently, the lack of flexibility in using such models. In engineering problems, they often have domain knowledge, side information, parameters, constraints, etc. To develop efficient neural-network-based solutions they first need to have a systematic way to train and use neural networks in the presence of such external knowledge. Zheng's group has made progress in that regard. They developed a geometric theory to evaluate the semantic information carried by the intermediate processing results within a deep neural network, which is a significant conceptual generalization of the conventional information theory. Based on these measurements, geometric operations are applied to separate and combine information according to the needs of specific use cases. Zheng's group has developed several solutions with this general method, including physical layer detections in wireless communications, network monitoring, and resource allocation algorithms, information security solutions for networks under malicious attacks, as well as using specialized neural network models to process long-time sequences.

BIOMEDICAL SCIENCE AND ENGINEERING

Elfar Adalsteinsson's lab developed an efficient, motion-robust machine learning framework for so-called slice-to-volume reconstruction in MRI, motivated by the assessment of fetal brain development. A slice-to-volume registration transformer performs inter-slice motion correction by simultaneously predicting rigid transformations of all images in 3D space, followed by reconstruction via implicit neural representation, where the underlying volume is represented by a continuous function of 3D coordinates. They demonstrated robust and efficient volumetric reconstructions and visualization of fetal MRI.

Bioelectronics Group, led by **Professor Polina Anikeeva**, creates technologies to study cell signaling in the brain and the peripheral organs. Last year Bioelectronics group developed novel magnetoelectric nanomaterials that transduce weak magnetic signals to electrical potentials suitable for neuronal activation. These particles are composed of magnetite (Fe_3O_4) nanodisc cores (~230 nm in diameter and ~40 nm thickness) that are then coated with ~ 5 nm shells of magnetostrictive cobalt ferrite ($CoFe_2O_4$) and piezoelectric barium titanate ($BaTiO_3$). The anisotropic architecture and spring-exchange interaction between the magnetite and cobalt ferrite yield to >1000 enhancement in magnetostriction coefficient as compared to isotropic materials, which then translates to record magnetoelectric coupling in the colloidal nanodiscs. When applied to neuronal membranes these magnetoelectric nanodiscs permitted remote activation of calcium influx in response to combined offset and alternating magnetic fields. Notably, these nanodiscs are sufficient to drive neural activity and behavior in mice in the presence of the combined magnetic fields (*Kim et al. accepted Nature Nanotechnology 2024*).

Professor Dennis Freeman's group focuses on understanding the physical mechanisms that are important in both normal and impaired hearing. Recent efforts have focused on the mechanisms by which cells in the inner ear are stimulated by motions of the tectorial membrane, which is a gelatinous structure that overlies and thereby transmits sound-induced motions to the mechanically sensitive hair bundles of the sensory receptor cells. In classical conceptions, the tectorial membrane is assumed to be mechanically stiff, and its motions are represented by a rigid plate. However, the tectorial membrane is a gel, and approximately 97% of its volume is water. Thus, motions of the tectorial membrane are resisted by both mechanical forces that arise in the stretching and compression of the proteinaceous matrix that comprises 3% of the volume of the tectorial membrane as well as by the flow of water through the porous structure of that matrix. During the past year, the group has measured the effects of hydrodynamic forces on tectorial membrane motion and has found phase leads as high as 90 degrees. Such phase leads are expected to sharpen frequency selectivity and increase the sensitivity of hearing. The group is currently making measurements in mice to assess the importance of this mechanism in genetic disorders of hearing.

Professor Martha Gray leads the Biomedical Technology Innovation Group. Her research program focuses on formalizing approaches that drive innovation to create impact through combined research and professional development of early career individuals, under the auspices of MIT IinQ, an open organization comprising programs that seek to change the paradigm for research and training. In 2024 we continued to deepen our partnership with the VHA, grew the nascent Catalyst Europe, and began work extending the Catalyst model to the area of energy and climate.

Professor Jongyoon Han leads the Micro/Nanofluidic BioMEMS Group. Their research focuses on molecular and cell separation and sorting technologies, as well as various novel microfluidic and BioMEMS systems. In 2024, they published a seminal paper on an inertial cell separation device that can reduce the amount of risky, potentially cancerous cells from stem-cell-derived cell therapy products, therefore enhancing the safety of regenerative medicine derived from induced pluripotent stem cells (iPSCs) [1]. The inertial cell separation system used in this work was originally developed in Singapore's SMART center (BioSyM & CAMP IRG) around 2011, and since then, it has been applied to many applications, such as cancer cell sorting, and mesenchymal stromal cell sorting.

> [1] Tan Dai Nguyen, Wai Hon Chooi, Hyungkook Jeon, Jiahui Chen, Daniel Ninio Roxby, Jerome Tan Zu Yao, Cheryl Yi-Pin Lee, Shi-Yan Ng, Sing Yian Chew, Jongyoon Han, "Label-free and high-throughput removal of residual undifferentiated cells from iPSC-derived spinal-cord progenitor cells," Stem Cells Translational Medicine, 13, 387–398 (2024), also featured in MIT News.

Professor Laura Lewis and the Lewis Lab develop new approaches to measuring human brain function using MRI and apply them to understand how the brain generates sleep, and why sleep is so important for brain function. This year, they created a new signal processing strategy for discovering the timing of hemodynamic signals in brain imaging data and using this information to enable analysis of precise timing information about human brain activity. They also developed a new MRI sequence for the detection of slow cerebrospinal fluid flow throughout the human brain, which is essential for brain health and has not previously been possible to image. This technology is now allowing us to study fluid flow in the human brain and test how we can enhance this flow to avert the risk of neurodegenerative disorders such as Alzheimer's disease.

In addition, they are developing strategies to discover the key brain regions that control sleep in humans. They developed a machine learning method that can predict brain activity across different sleep depths, using fMRI data. They found that this tool now allows us to uncover the key networks that are most important for predicting distinct stages of sleep and wakefulness, unraveling the brain circuits that regulate and generate sleep.

Senior Researcher Stefanie Shattuck-Hufnagel and team continue modeling human speech perception, prosodic structure (intonation and timing), and speech production planning by developing a system for characterizing the phonetic habits of different individual speakers, dialects, and languages, using Cue Production Profiles and documenting multimodal aspects of speech production, including not only words and syntactic structure but also prosody and co-speech gesture. Shattuck-Hufnagel has co-authored a prosodic analysis manual and a website on gesture analysis and is co-editing a special issue of the Journal of the Acoustical Society of America on the role of individual acoustic cues to contrastive sounds in speech processing.

Professor Charles Sodini advises the MIT Medical Electronic Device Realization Center (MEDRC) which seeks to revolutionize medical diagnostics and treatments by bringing health care directly to the individual and to create enabling technology for the future information-driven healthcare system. The MEDRC serves as a focal point for engagement with researchers across MIT, the medical device and microelectronics industries, venture-funded startups, and the Boston medical community.

Professor Sixian You and the Computational Biophotonics Group's research focuses on advancing the understanding and treatment of complex human diseases by novel optics and algorithms. The most exciting results include 1) achieving deeper (3x) and dynamic metabolic imaging in living organisms by using a modular fiber source, which is being used to assess metabolic responses in liver organoids for potential drug discovery (Under Revision, Science Advances); 2) overcoming intrinsic axial blurring by physics-based AI for 3D clearer microscopy, which is being used to assess subcellular features in human endometrium tissue for deeper understanding of endometrium spatiotemporal dynamics (Under Revision, Nat Comm); and 3) developing uncertainty-guided adaptive imaging scheme to achieve photon-efficient high-quality imaging (Under Review, Light Science & Application).

Professor George Verghese's Computational Physiology and Clinical Inference Group, collaborating with Prof. Thomas Heldt, has brought to fruition its multi-year study of *capnography*, which records CO2 concentration in exhaled breath as a function of time (temporal capnography) or of expired volume (volumetric capnography). Temporal capnography is performed minimally intrusively during normal breathing and is widely available. Volumetric capnography requires capturing and measuring airflow alongside CO2 concentration and is thus limited to pulmonary function testing labs or to ventilated patients. The group's latest paper on capnography, published in the September 2023 *IEEE Transactions on Biomedical Engineering*, presents low-order physiologically based mechanistic models that closely and quantitatively account for both temporal and volumetric capnograms. Model parameters corresponding to best fits of model outputs to measurements provide clinically useful patient-specific information. Using data from ventilated patients, the paper also verifies that temporal capnography allows estimation of the entire exhaled airflow profile, to within a scaling, which suggests new tests for distinguishing among common cardiorespiratory diseases using temporal capnography alone.

Another multi-year project was recently brought to fruition with the August 2023 publication of the second edition of *Principles of Power Electronics* by Professors John Kassakian, David Perreault, and George Verghese, joined by Dr Martin Schlecht. This edition constitutes a major revision and expansion of the 1991 first edition. Professor Verghese primarily contributed a part of the book (out of the four parts) dealing with dynamic models and control in power electronics; the treatment is broader and quite distinct relative to other texts.

NANOSCALE MATERIALS, DEVICES AND SYSTEMS

Assistant Professor Suraj Cheema joined MIT as an assistant professor in a joint appointment between the Department of Materials Science and Engineering and the Department of Electrical Engineering and Computer Science in July 2024. His research explores ferroelectric materials and devices to discover new paradigms of energy-efficient computing and energy-autonomous technologies toward more sustainable microelectronics. His group focuses on the atomic-scale design of materials already in modern microelectronics to engineer unprecedented electronic properties and to accelerate the translation of next-generation electronic devices, spanning ultrahigh energy storage capacitors to ultralow-power logic transistors. During this reporting period, as a Visiting Scientist in RLE and in collaboration with MIT Lincoln Laboratory, Suraj led work on new micro-capacitors for on-chip energy storage that can charge chips 100 million times faster than commercial Li-ion micro-batteries (*Nature-2024*). Additionally, Suraj's work on energy-efficient logic transistors (also integrated with MIT Lincoln Laboratory's foundry) was just awarded a program with GlobalFoundries for integration into their next-generation fin field effect transistor (FinFET) logic technology. These two works can help mitigate the exponential rise in global energy consumption derived from computing, artificial intelligence (AI), and Internet-of-Things (IoT) devices towards more energy-sustainable microelectronics.

The Quantum Nanostructures and Nanofabrication group, led by **Professor Karl K. Berggren** and **Principal Research Scientist Dr. P. Donald Keathley** investigates (1) superconducting nanotechnologies, (2) nanoscale nonlinear optical electronics devices, and (3) the interactions of elementary particles with nanostructures for lithography, microscopy, and light generation. In superconducting nanotechnologies, they gained significant results in the demonstration of superconducting nanowire single-photon detectors integrated onto lithium niobate waveguides (ACS Photonics 11, 356–361 (2024)). In nanoscale nonlinear optical-electronic devices, they were able to demonstrate lightwave-electronic harmonic frequency mixing (Science Advances 10, eadq0642 (2024)).

Professor Dirk Englund leads the MIT Quantum Photonics and AI Laboratory. Their research aims to understand and bridge gaps between today's technology and the theoretical limits given by quantum mechanics and information theory. The team had four key technologies and advances during this reporting period: quantum computing, quantum networks, quantum sensing, and machine learning. In quantum computing, they developed a new generation of "atom-control photonics integrated circuits" ("APICs") for scalable coherent control of atomic memories in silicon photonics, thin-film lithium niobate, and in strain-actuated silicon nitride; moreover, the group developed algorithms and hardware for "full-degree-of-freedom" modulation of optical fields, and a new scheme for geometric quantum error correction. In quantum networks, they developed microeconomic theory for "quantum utility" and introduced scalable quantum routing and error correction protocols for globe-spanning quantum networks with error correction. In quantum sensing, in collaboration with Dr. Matt Trusheim at Harvard University, they developed methods for selective cooling of microwave fields. You could think of this as the "anti-microwave" oven. This resulted in the first ambient-operation solid-state magnetometer with better than pT/Hz^½ resolution. In machine learning, in collaboration with visiting scientist Ryan Hamerly, Senior Scientist at NTT Research, they developed machine learning accelerators with record compute density (Nature Photonics), ultra-high throughput (Science Advances), distributed edge computing (Science), and theory for transferable machine learning on analog systems.

PHOTONIC MATERIALS, DEVICES AND SYSTEMS

Professor Marc Baldo's research program currently centers on solar cells, light-emitting devices, chemical sensors and spintronic switches. A recent key research accomplishment is their demonstration of coupling between silicon solar cells and singlet exciton fission in the molecular semiconductor tetracene. A new, rationally-designed interface has demonstrated an increase in photocurrent from silicon due to singlet exciton fission for the first time. In the quest for solar cells that exceed the conventional single junction thermodynamic limit, we believe that this is the first example of a successful technology that boosts current rather than voltage. The corresponding cell architecture promises to be significantly easier to manufacture than comparable 'tandem' solar cells that increase voltage by building a second cell on top of the original solar cell. This year, the team will attempt to demonstrate the first silicon cell capable of generating more than one electron per photon in the visible spectrum. A second result is the stabilization of organic light emitting molecules by tuning the excited state lifetime. During the last year, they demonstrated that the instability of commercial OLEDs is dominated by the formation of dark triplet excitons in the blocking layers surrounding the emission zone. Finally, in collaborative work with Prof. Mircea Dinca (MIT, Chemistry) they have demonstrated a new chemical sensor design based on alloys of metal organic frameworks that is capable of correctly classifying chemical species at varying concentrations. This year, they will attempt to use this approach to classify materials within mixtures.

The Accelerated Materials Laboratory for Sustainability (AMLS) led by **Professor Tonio Buonassisi** in Mechanical Engineering works to rapidly develop & scale novel materials using a combination of artificial intelligence, automation, simulation, and soft skills. In April 2023, Prof. Buonassisi, along with Prof. Vladmir Bulovic and Prof. Moungi Bawendi**,** were awarded a ~$10M DOE-sponsored national grant for the newly formed Accelerated Co-Design of Durable, Reproducible, and Efficient Perovskite Tandems research center (ADDEPT), focused on developing the next generation of perovskite-based tandem solar cell. It is now entering its second year after a successful continuation application. [https://news.mit.edu/2023/moving-perovskite-advancements-lab-manufacturing-floor-0420.

The AMLS was also selected for an additional $300k Massachusetts Clean Energy Center (MassCEC) award. Additionally, the AMLS team was featured in the MIT News and Technology Review for developing a computer-vision tool to enable autonomous, self-driving labs to characterize order 1000 samples per minute. https://news.mit.edu/2024/new-computer-vision-method-helps-speed-screening-electronic-materials-0611. As the facilities infrastructure is becoming a major bottleneck to continued research progress, Buonassisi is working with the MechE department to collect data from Building 35, to motivate substantial investments.

For their Advanced Research Projects Agency, Energy (ARPA-E) project on Low Energy Nuclear Reactor (LENR), **Professor Peter Hagelstein** and his group designed a LENR current-controlled neutron generator and have started constructing it. They designed an efficient graphite moderator He-3 neutron detector to monitor neutrons for this experiment and others. A major effort to document my LENR model got started in January, and this effort has led to several innovations including a new mechanism that takes advantage of differences in loss in the different pathways to reduce destructive interference in excitation transfer; numerical calculations for nuclear transitions matrix elements for the relativistic phonon-nuclear interaction for $D_2/^4He$ transitions; development of a new hybrid part-coherent and part-incoherent scheme for excitation transfer from the $D_2/^4He$ fusion transitions; and quantitative evaluation of the fusion rate in the new scheme. This research is focused on developing a quantitative theoretical understanding of the effect and developing an unequivocal reproducible experimental demonstration of LENR anomalies in the lab.

Professor Qing Hu studies terahertz quantum cascade lasers and electronics; sensing and real-time terahertz (THz (T-rays)) imaging using quantum cascade lasers and focal-plane cameras. His group has achieved many world records in terms of performance of their THz quantum cascade lasers including but not limited to the highest operating temperature in the pulsed mode ~261 K. This achievement was made following an earlier breakthrough in reaching 250 K, and resulted was hailed by reviewers at Nature Photonics as "an exciting breakthrough", "a major milestone for THz photonics", and "a significant breakthrough result". His group has performed real-time THz imaging at a video rate of ~20 frames/second. They have developed a novel tuning mechanism that is qualitatively different from all the other tunable lasers and has achieved continuous tuning over a broad frequency range (~330 GHz).

More recently, they have developed the first THz laser frequency combs and demonstrated dual-comb spectroscopy. These are experiments with the potential to lead to improvements in sensing, imaging, and high-bandwidth communications. In 2021-2022, they developed and delivered local oscillators for the OI spectral line at 4.74 THz for the Gal/Xgal U/LDB spectroscopic-stratospheric terahertz observatory program (GUSTO). This ultra-long duration (>100 days) balloon-based THz observatory will be launched at the end of 2022. The extensive mapping of the important OI line will provide information and shed new light on star and galaxy formation. Following their breakthrough in the development of THz laser frequency combs, they have extended the success to the important long-wave infrared (LWIR, 8-13 μm wavelength) range, where it is rich in spectral fingerprints and coincides with a highly transmissive atmospheric window. Dual-comb spectrometers in this wavelength range will have important applications in remote sensing and spectroscopy.

Professor Luqiao Liu and his team have been focused on investigating new materials for useful memory and logic devices. Specifically, they have made the following major achievement: they discovered an efficient mechanism to electrically read out the magnetic state from an antiferromagnet–magnetic material with canceled magnetic moments from two competing spin lattices [Nature Communication, in press]. Traditionally it was believed that antiferromagnets cannot carry spin current due to their zero net moment and, therefore will not exhibit finite magnetoresistance for useful magnetic reading operations. Liu’s study reveals the important role of symmetry breaking in yielding a large antiferromagnetic tunneling magnetoresistance, which provides an efficient reading mechanism for magnetic memory and spin logic. This, in combination with the writing mechanism that they discovered earlier, paved the avenue for useful antiferromagnetic spintronics.

John Joannopoulos and Marin Soljacic work together as a team in the area of nanophotonics. In this work (1), their research focuses on developing new plasmonic materials by creating defective lattices in hexagonal boron nitride (hBN). These materials exhibit strongly confined plasmonic excitations, which are collective oscillations of free electrons stimulated by light. Such materials are promising for various technological applications, including sensors and high-resolution imaging because they can control light on scales smaller than its wavelength. Traditional plasmonic materials often suffer from significant energy losses, shortening the lifespan of plasmonic excitations. The study tackles this issue by introducing carbon atoms into hBN, forming a structured defect that alters the electronic properties of the material. This method helps produce plasmons with minimal energy loss and enhanced confinement. Their theoretical predictions using density functional theory show that these new materials can achieve much higher quality factors than conventional plasmonics, suggesting they could lead to more efficient and compact devices. The findings open up possibilities for engineering low-loss, highly confined plasmonic devices that bridge the gap between electronic and photonic technologies [1].

[1] Ali Ghorashi, Nicholas Rivera, Bowen Shi, Ravishankar Sundararaman, Efthimios Kaxiras, John Joannopoulos, Marin Soljacic. Phys. Rev. Materials Vol.8, L011001 (2024).

Professor Jing Kong and the Nano-Materials and Electronics Group focus on developing chemical vapor (CVD) synthesis of various 2D materials, characterizing their structures, properties and developing their applications. Highlights include understanding the role of a H2-free environment during temperature ramping in the synthesis of 2D transition metal dichalcogenides (TMD), to boost the synthesis of monolayer TMDs in the CVD synthesis. A second is the development of heterostructure resonators based on hexagonal Boron Nitride (hBN) and graphene, the phonon polaritons in deposition hBN hybridize with graphene plasmons and make these mixed phonon polariton modes in hBN very appealing, enabling active control of electrodynamic properties with a reduction of propagation losses. Optical resonators were added to confine the hybridized plasmon–phonon polaritons deeply into the subwavelength regime, featuring high quality factors. The large-scale CVD synthesis offers a scalable approach for the resonators.

By enabling the integration of millions of micro-scale optical components on compact millimeter-scale chips, silicon photonics is positioned to enable next-generation optical technologies that facilitate revolutionary advances for numerous fields spanning science and engineering. **Professor Jelena Notaros's** group is developing novel silicon-photonics-based platforms, devices, and systems for high-impact applications including augmented-reality displays, chip-based 3D printers, trapped-ion quantum systems, biophotonic optical tweezers, underwater optical communications, and LiDAR sensors for autonomous vehicles.

QUANTUM COMPUTATION AND COMMUNICATION

Professor Paola Cappellaro and her group introduced innovative protocols for networked, quantum-enhanced sensing and for robust many-body dynamics. By exploiting a spin coupled to an optically-active quantum probe, they were able to characterize and control far-away spins, beyond the quantum survival time of the probe. The larger network of qubit sensors could measure spatial and temporal correlations. Ph.D. candidate Minh-Thi Nguyen developed a method to detect rotations with nuclear spin associated with spin defects. The coupling to the spin defect can provide up to a thousand-time enhancement of the signal, thus enabling a practical quantum spin gyroscope.

Finally, they were able to experimentally demonstrate a time crystal, a phase of matter that breaks time-translation symmetry with an emerging periodic structure. They developed control to alter the nuclear spins interaction strength, thus constructing a phase diagram for the conditions under which a time crystal would either exist or "melt". In cases where time-crystalline order emerged, the quantum system persisted for exceptionally long times, which is unusual for systems out of equilibrium at relatively high temperatures and could be exploited for future quantum devices.

Professor William D. Oliver, Research Scientists Dr. Jeff Grover and Dr. Joel Wang, and Professor Terry Orlando direct the Engineering Quantum Systems (EQuS) group, a multi-disciplinary research effort that focuses on using superconducting circuits for quantum computation. Their research uses advanced techniques of quantum control and noise spectroscopy to characterize and improve the performance of superconducting qubits. The work is performed in close collaboration with Group 89 at MIT Lincoln Laboratory. This past year has been productive: they published 7 manuscripts and posted another 9 to the quantum physics arXiv. They directly measured how often cosmic-ray muons can cause catastrophic errors in quantum processors. They used microwave techniques to probe the nature of superconductivity in twisted bilayer graphene. They created remote entanglement between separate quantum chips using a novel chiral quantum interconnect. They also used our 16-qubit simulator to create synthetic electric and magnetic vector potentials, which could help realize interesting topological states.

CONDENSED MATTER PHYSICS

Research in **Professor Joseph Checkelsky** laboratory in the last year has focused on the synthesis and study of new quantum materials. This includes stabilizing new single-crystal materials with ultrahigh electronic quality and epitaxial thin film structures of materials not otherwise stable in nature. Further, they have also used computational methods to accelerate this materials search and synthesis campaign.

They are developing new methods for encapsulated synthesis to achieve and retain high electronic quality in materials. In the last year, they established new material structures that promote electronic interactions by trapping states in confined dimensions and quenching kinetic energy with tailored lattice motifs. This has yielded interacting, magnetic, and superconducting phases. These activities bridge the fields of materials science, physics, and chemistry. Progress in these new approaches to identifying and synthesizing new materials may have an impact across these disciplinary boundaries. Checkelsky group members trained in these pursuits are gaining practical experience and expertise in this interdisciplinary setting.

Over the past year, **Professor Riccardo Comin** and his group investigated a diverse array of two-dimensional magnets and multiferroics, focusing on specific properties of these fascinating functional quantum materials. Their most notable achievements include demonstrating electrical switching in an unconventional magnet with odd-parity spin polarization. They accomplished this using nickel iodide (NiI2), an insulating van der Waals chiral multiferroic. NiI2 possesses robust, non-relativistic spin splitting, controllable via its coupling to ferroelectric order. This material belongs to a novel class of "altermagnets," holding potential for future spintronics applications. Additionally, they unveiled the properties of magnetic excitons in two 2D magnet families: nickel dihalides (NiX2) an.000d. 00c0h00000000r…0000o0m0i0.0u.000m s0ulfur bromide (CrSBr). In nickel dihalides, they observed spectrally sharp and tunable magnetic excitons with optically addressable spin degrees of freedom. These systems could enable optical control and detection of magnetic order, paving the way for applications in quantum information processing, such as molecular qubits.

In CrSBr, they discovered two excitons whose fundamental energies are remarkably sensitive to the underlying magnetic order. The sharpness and intensity of these excitons turn nanoscale CrSBr flakes into optical cavities, capable of trapping specific light wavelengths. The trapped photons interact with the excitons, leading to polariton formation with an ultra-strong photon-exciton coupling. This regime could be exploited to achieve magnetic-field control of cavity modes in nanophotonic devices.

Professor Nuh Gedik and the Gedik group investigated a magnetic material in which neighboring magnetic spins point in opposite directions, known as antiferromagnets. These materials hold promise for creating faster and more compact magnetic memory and information processing devices. However, controlling antiferromagnets has challenges, such as their extremely weak response to external magnetic fields.

To address this, they employed a unique approach using intense and ultrashort terahertz (THz) pulses. The frequency of these pulses is matched with the natural frequency of large atomic vibrations. After laser excitation, the atoms in the material oscillate in a synchronized manner, thereby altering the distances between atoms. Since the magnetic interactions in these materials depend on these atomic distances, this approach also affects their magnetic properties. What we discovered is that such a method created a new magnetic state, with a finite magnetization, which lasted for a remarkably long time even after the THz light was turned off. The paper reporting these results was just accepted by Nature.

In 2023-2024, the Ju group, led by **Assistant Professor Long Ju**, made several breakthroughs in the field of condensed matter physics. This field is known as solid-state physics and formed the basis of all electronic and photonic applications.

Specifically, the group discovered that the simplest form of solid-state materials, graphite, can exhibit the most exotic physical properties. For example, electrons, as the basic unit of electrical charge, interact with each other strongly and appear as if they carry fractional charges in five-layered graphene flakes [1][2]. Such fractional charges realize the so-called fractional quantum anomalous Hall effect for the first time, together with another material discovered in the same year. This groundbreaking discovery has important implications for topological quantum computing.

In another example, the same five-layered graphene, when influenced by a neighboring semiconductor layer, opens up channels for electron conduction that are dissipation-less [3][4]. These channels are like highways for cars, where the electrons can move without being slowed down by traffic lights. This discovery could facilitate unconventional low-power electronics.

Together with other significant discoveries, our efforts have created a new sub-field that is now attracting much attention from physicists all around the world. This material system is distinct from the so-called magic-angle-bilayer-graphene, discovered by a colleague in the MIT Physics Department in 2018.

[1] Nature 626 (8000), 759-764. [2] https://news.mit.edu/2024/electrons-become-fractions-graphene-study-finds-0221. [3] Science 384 (6696), 647-651.
[4] https://news.mit.edu/2024/physicists-create-five-lane-superhighway-electrons-0604;
[5] Nature 623 (7985), 41-47. [6] Nature Nanotechnology 19 (2), 181-187.

One focus of **Professor Senthil Todadri** and his team has been on the theory of quantum phases of electronic matter in Moiré materials. An interesting recent development in this area is the observation of phenomena known as the quantum Hall effects. The new results show that these phenomena can happen in the absence of any magnetic field in time-reversal invariant systems, unlike previous observations over the last 4 decades. This raises a host of fascinating theoretical questions that their group addressed. A surprising discovery was the observation of the integer effect (in addition to the fractional one) in certain multilayer graphene materials where free electron theory predicts that at the corresponding charge density these materials are metals, and not quantum Hall insulators. They developed a microscopic theory of the observed integer effect, showing how electron-electron interactions lead to the quantum Hall insulator. This surprising mechanism provides a foundation to address intricate questions surrounding the fractional state. In earlier work, they developed a quantum Ginzburg-Landau theory to address the interplay between fractional quantum Hall states and more conventional states (such as charge ordered insulators, or Landau fermi liquids). They applied the theory to address phase transitions and universal aspects of the anyons of the fractional quantum Hall state. Other work from the group includes a proposal for the existence of an unusual critical point inside the familiar Neel state of two-dimensional quantum antiferromagnets, and some results on how fractionalization of the electron charge can occur in some lattice systems.

PERSONNEL

RLE Headquarters (HQ) had eight staff promotions. **David Barnett** was promoted to Senior Fiscal Officer**, Catherine Bourgeois** was promoted to Administrative Services Manager, and **Amanda Keyes** was promoted to Project Coordinator. **Flor Nawara** was promoted to Manager of Human Resources, **Matt McGlashing** was promoted to the level of Senior Mechanic, and **Paul Palei** was promoted to Senior Systems Engineer. **Melissa Sheehan** was promoted to Senior Manager for Financial Administration, and **Sampson Wilcox** was promoted to Media Design & Web Content Manager.

RLE HQ also had three new hires during this reporting period. **Sarah Bryce** is an Assistant Fiscal Officer, **Hailey Weinstein** is a Human Resource Representative I, and **KeKe Xu** is a Fiscal Officer. Fiscal Officer, **Kristan Cook**, left RLE HQ for a new position in Biological Engineering (BE).

FACULTY HONORS AND AWARDS

Marc Baldo was elected to the National Academy of Engineering.

Karl Berggren was named a 2024 MacVicar Faculty Fellow, which recognizes exceptional undergraduate teaching.

Tonio Buonassisi received the distinction of CIFAR Fellow in 2023, Clarivate Highly Cited in 2023 and is now an IEEE Senior Member.

Paola Cappellaro was awarded the APS fellowship in Atomic Molecular and Optical Physics.

Vincent Chan is the 2024 recipient of the IEEE Thomas Edison Medal for *"pioneering technical contributions and leadership in the fields of space and terrestrial optical communications and networks."*

Suraj Cheema was awarded the 2023 APS Richard Greene Dissertation Award in Experimental Condensed Matter Physics, the MIT.nano Young Faculty Award (2023), and the RLE Early Career Development Award (2024).

Kevin Chen has received the NSF CAREER award, the Steven Vogel Young Investigator Award, and has been promoted to the rank of associate professor without tenure.

Luca Daniel - 2023 Bose Fellow, for a research proposal with the most risky, controversial, cross-disciplinary originality of vision; IEEE Antenna and Propagation Society Wheeler Applications Prize Paper Award (for best paper of the year 2023 in IEEE Trans. on Antennas and Propagation): 2024 Graduate Teaching Award for the MIT Schwarzman College of Computing (selected by the MIT Graduate Student Council).

James Fujimoto received the National Medal of Technology and Innovation **in October 2023.**

Dirk Englund was promoted to full Professor in 2023. He continued his technical advising roles with the Department of Energy in quantum information science; his tenure with the DARPA Microsystems Exploration Council (MEC); and with spin-out companies Dust Identity, LightMatter, QuEra Computing, and Quantum Network Technologies, which jointly employ over 100 scientists and engineers, mostly located in the Boston area and San Francisco bay area. Englund was again named a “Highly Cited Researcher” by Web of Science. In addition, Englund founded a new company, Axiomatic-AI, whose Automated Interpretable Reasoning (AIR) system is grounded in evidence-driven deduction based on the foundations of physics and mathematical deduction.

Nuh Gedik received the 2024 National Ross Brown Investigator Award to develop a new kind of microscopy that images electrons phot-emitted from a surface while also measuring their energy and momentum.

John Joannopoulos received the 2024-2025 James R. Killian Jr. Faculty Achievement Award from MIT in May 2024.

Jeffrey H. Lang and David J. Perreault’s paper, “A piezoelectric-resonator-based dc-dc converter demonstrating 1 kW/cm^3 resonator power density” (*IEEE Transactions on Power Electronics*, *38*, 3, 2811-2815, March 2023) by J. D. Boles, J. E. Bonavia, J. H. Lang, D.J. Perreault, in 2024 received a Prize Letter Award.

Farnaz Niroui was promoted to Associate Professor Without Tenure and received the Junior Bose Award for Teaching Excellence.

Jelena Notaros received the 2023 MIT Louis D. Smullin (1939) Award for Teaching Excellence, the 2023 Optica FiO Postdeadline Paper, (as PI), the 2023 SRC JUMP CogniSense Best Demo Award and Best Poster Award (as PI), and 2024 Optica CLEO Highlighted Talk Award (as Co-PI).

Senthil Todadri was elected to the National Academy of Sciences in 2024.

Tess Smidt was honored with the 2024 Air Force of Science Research (AFOSR) Young Investigator Award.

Marin Soljacic was Highly Cited Researcher in 2023 according to Web of Science.

David Trumper received the American Society for Precision Engineering (ASPE) Distinguished Service Award in 2023.

Sixian You received the 2024 NSF CAREER Award.

Vladan Vuletic was elected Fellow of the American Association for the Advancement of Science (AAAS) and continues to be selected as a Clarivate Highly Cited Researcher (2024). He serves as the Director of the NSF Frontier Center for Ultracold Atoms as well as the Chair Elect of the Division of Atomic Molecular and Optical Physics (DAMOP) of the American Physical Society.

STAFF AWARDS

Cindy Matheson, Manager of Resource Development, received the 2024 Infinite Mile Award.

RLE STUDENT AWARDS

There were two winners for the **2024 Helen Carr and William T Peake Prize**; a memorial fund in honor of Helen and William Peake, that was established with a generous gift from Dr Sheldon Pang, an alumnus of the Research Laboratory of Electronics (RLE) and its affiliated Eaton-Peabody Laboratory (EPL), an inter-institutional research center of the Massachusetts Institute of Technology (MIT), Harvard Medical School (HMS), and the Massachusetts Eye and Ear Infirmary (MEEI). The first was awarded to **Yunchan Hwang, supervised by James Fujimoto for his** research studying the vasculature of the human retina, a tissue responsible for visual perception by developing advanced Optical Coherence Tomography Angiography (OCTA) techniques to study retinal blood flow in vision-impairing diseases such as diabetic retinopathy. The second was awarded to **Christopher Buswinka**, PhD student conducting research in the lab of **Artur Indzhykulian** at the Eaton-Peabody Laboratories at Mass Eye and Ear and Harvard Medical School, was also a recipient of the Peake Prize for his research exploring the application of deep learning computer vision techniques for microscopy analysis in the inner ear. The Peake Prize is

There were two winners for the **2024 Claude E Shannon Research Assistant Fellowship**: a memorial fund supporting one year of graduate research work in the field of communications in honor of Claude E Shannon. **Soroush Araei,** supervised by Negar Reiskarimian for his research in advancing communication technologies for next-generation wireless networks, particularly 5G and beyond, by addressing interferers, which have significantly hindered the development of an all-in-one communication receiver capable of supporting 5G and other existing applications, and **Tejas Jayashankar,** supervised by Gregory Wornell for his research on leveraging machine learning and generative models to advance technologies in compression, signal separation, and synthesis addressing the long-standing challenge of efficient signal compression in the modern context of big data and augmented reality, received this esteemed award.

OTHER STUDENT AWARDS

Vaishnavi L. Addala, G supervised by William Oliver, has been awarded the Department of Energy (DOE) Computational Science Graduate Fellowship.

Maitreyi Ashok, G supervised by Anantha Chandrakasan received an International Solid-State Circuits Society (ISSCC) Rising Star Award in January 2024.

Julia Balla, G supervised by Tess Smidt, received the National Defense Science and Engineering Graduate (NDSEG) Fellowship.

Cora Barrett, G, and **Gabriel Cutter**, G, supervised by William Oliver, were awarded the National Science Foundation Graduate Research Fellowships.

Jacob Beckham, G supervised by Polina Anikeeva received the Schmidt Science Fellow Award.

Honghao Cao, G, supervised by Sixian You, received the Society of Photo-Optical Instrumentation Engineers (SPIE) Photonics West Biomedical Optics (BiOS) Multiphoton Best Poster Award in 2024.

Nicholas Cicero, G supervised by Laura Lewis, received the National Institute of Health (NIH) Individual Fellowship (F31) Award.

Ahmet Kemal Demir, G supervised by Riccardo Comin, received a Mathworks Fellowship Award.

Harrison Fisher, G supervised by Laura Lewis, received the National Science Foundation Graduate Research Fellowship Award.

Giulianna Hashemi-Asasi, G supervised by Tess Smidt, received the National Defense Science and Engineering Graduate (NDSEG) Fellowship Award.

Ching-Yun Ko, G supervised by Luca Daniel, was the invited speaker at the University of California of Los Angeles (UCLA) Synthetic Data Workshop, 2023, title: Task-Agnostic Benchmarking of Pretrained Representations Using Synthetic Data.

Mit Kotak, G supervised by Tess Smidt, received the (NSF) Graduate Research Fellowship.

Kunzan Liu, G, supervised by Sixian You, received the Koch Institute Imaging Award.

Narumi Nagaya Wong, G, co-advised by Marc Baldo in EECS and William Tisdale in ChemE, won first place in the Artificial Intelligence Chemical Engineering (AIChE) Area 8E Graduate Student Award competition for her presentation on interfacial engineering for singlet fission sensitization of silicon in November 2023.

Keisuke Nagao, G supervised by Polina Anikeeva received the Eva Tan Molecular Therapeutics Fellowship.

Minh-Thi Nguyen, G supervised by Paola Cappellaro, was awarded an NSF Graduate Student Fellowship.

Atharva Sahasrabudhe G supervised by Polina Anikeeva received the Materials Research Society (MRS) Graduate Silver Award.

Peter Satterthwaite, G supervised by Farnaz Niroui, received the EECS MathWorks Fellowship.

Xavier Smith, G supervised by Polina Anikeeva received the National Science Foundation (NSF) Graduate Research Fellowship (GRFP).

Stephanie Williams, G supervised by Laura Lewis, received the National Defense Science and Engineering Graduate (NDSEG) Department of Defense (DoD) Exemplary Presentation Award.

Matthew Yeung, G supervised by Karl Berggren, was awarded the Ascend Post-Doc Fellowship by the NSF.

Chia-Chin Tsai, G supervised by William Oliver, received the Think Global Education Trust Scholarship in 2024.

Elizabeth Whittier, G supervised by Polina Anikeeva received the Neurobiological Engineering Training Program Fellowship.

Cassandra Ye, EECS Super Undergraduate Research Opportunity Program (UROP) student, supervised by Sixian You, received the SPIE Photonics West BiOS Best Paper Award in 2024.

Li-Yu Yu, G supervised by Sixian You, received the SPIE Photonics West BiOS Hitachi High-Tech Best Presentation Award in 2024.

Zinong Yang, G supervised by Laura Lewis, received the Organization for Human Brain Mapping (OHBM) Merit Abstract Award in 2024.

OUTREACH

Kevin Chen and his research team led a variety of outreach programs, such as organizing interactive events including a display of microrobots at the MIT Museum and hosting visiting K-12 students. In addition, his research on micro-robotic bees is now on exhibit at the American Museum of Natural History in New York City.

Marc Baldo
Director, Research Laboratory of Electronics
Professor of Electrical Engineering and Computer Science

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