Institute for Soldier Nanotechnologies

The Institute for Soldier Nanotechnologies (ISN) is a U.S. Army-sponsored University-Affiliated Research Center (UARC). The ISN leverages the unique capabilities of the Army, industry, and MIT for the benefit of the Soldier and other U.S. warfighters.

The ISN works with Army colleagues to revolutionize the protection, survivability, and mission capabilities of military units by extending the frontiers of nanotechnology through fundamental research, and by transitioning promising research outcomes with the Army, other U.S. military services, industry, and MIT Lincoln Laboratory.

By working at size scales where intrinsic properties of matter become size-dependent, ISN research provides profound opportunities for new materials, phenomena, and properties that are otherwise unattainable.

A five-year contract renewing the ISN as a UARC became effective on March 1, 2023. An Army Cooperative Agreement funding 15 new ISN core research projects, with 22 MIT faculty members from 10 academic departments and one ISN Principal Research Scientist as Principal Investigators (PIs), became effective on July 1, 2023.

Headquarters Team

The ISN headquarters team are experienced professionals accomplished in the leadership and performance of university research, headed by a trio of senior executives.

Professor John D. Joannopoulos, Director; Francis Wright Davis Professor of Physics; Member, National Academy of Sciences; Member, American Academy of Arts & Sciences

- Professor Raúl A. Radovitzky, Associate Director; Jerome C. Hunsaker Professor of Aeronautics and Astronautics
- William A. Peters, PhD, Executive Director; Principal Research Engineer
- Franklin E.W. Hadley, Director, Outreach and Communications
- Joshua Freedman, Director, Finance and Administration; (In March 2023, Josh Freedman's title was changed from Assistant Director for Administration and Finance to Director of Administration and Finance in an MIT effort to standardize the titles of some personnel.)
- Ivan Celanovic, PhD, Principal Research Scientist
- Steve Kooi, PhD, Principal Research Scientist
- Amy Tatem-Bannister, Laboratory and Facilities Manager; Environmental Health and Safety Coordinator
- Donna Johnson, Research Support Associate, Environmental Health and Safety Representative
- Marlisha McDaniels, Executive Administrative Assistant

- John R. McConville, Program Manager, UARC Science and Technology Transitions; Office for Cross-Competency Program Integration; Army Research Office, U.S. Army Combat Capabilities Development Command Army Research Laboratory; (A Department of the Army civilian, John McConville expedites transitioning and is the ISN's de facto Army liaison.)

Two staff members departed the ISN in the past year. In December 2022, instrumentation specialist Nicole Bohn left the ISN to take a similar position at MIT.nano. In April 2023, research specialist and erstwhile ISN Soldier Design Competition coordinator Kurt Keville left MIT for a position at the University of Massachusetts Boston.

A search for a new instrumentation specialist led to the hiring of a new staff member soon after the submission of this report.

Principal Investigators

The ISN's fifth funding cycle (ISN-5) features a portfolio of 15 core research projects led by a total of 23 PIs. These PIs are:

- Mark Bathe, Professor of Biological Engineering
- Moungi Bawendi, Lester Wolfe Professor of Chemistry
- Ivan Celanovic, ISN Principal Research Scientist
- Dirk Englund, Associate Professor of Electrical Engineering and Computer Science
- Yoel Fink, Professor of Materials Science and Engineering; Professor of Electrical Engineering and Computer Science
- Peter Fisher, Thomas A. Frank (1977) Professor of Physics
- Liang Fu, Professor of Physics
- Ashwin Gopinath, Assistant Professor of Mechanical Engineering
- Paula Hammond, Institute Professor
- John Joannopoulos, Francis Wright Davis Professor of Physics
- Steven Johnson, Professor of Applied Mathematics; Professor of Physics
- Mathias Kolle, Associate Professor of Mechanical Engineering
- Jing Kong, Professor of Electrical Engineering and Computer Science
- Robert Macfarlane, Paul M. Cook Associate Professor of Materials Science and Engineering
- Bradley Olsen, Alexander and I. Michael Kasser (1960) Professor of Chemical Engineering
- Tomás Palacios, Clarence J. LeBel Professor of Electrical Engineering and Computer Science

- Carlos Portela, Brit (1961) and Alex (1949) d'Arbeloff Career Development Assistant Professor in Mechanical Engineering
- Raúl Radovitzky, Jerome C. Hunsaker Professor of Aeronautics and Astronautics
- Christopher Schuh, POSCO Professor of Materials Science and Engineering
- Marin Soljačić, Professor of Physics
- Michael Strano, Carbon P. Dubbs Professor in Chemical Engineering
- Timothy Swager, John D. MacArthur Professor of Chemistry
- Brian Wardle, Professor of Aeronautics and Astronautic

Research Portfolio

The ISN's research portfolio evolves to reflect areas where the ISN and the Army see the potential for exceptionally strong impacts. The current ISN-5 core research portfolio features five Strategic Research Areas (SRAs) subdivided into 15 projects, described below.

SRA 1: Photonics, Electronics, and Quantum Sciences

Project 1.1: Nanophotonics-Enhanced Systems

PIs: Johnson, Soljačić

Nanophotonics maximizes the potential to control and tailor the behavior of light, enabling many important applications. In Project 1.1, the Johnson and Soljačić research groups focus on exploring physics and designs by which nanophotonics can provide new capabilities for sensors and light sources of interest for Soldier applications, exploiting new theoretical ideas, computational algorithms, and emerging experimental platforms.

Project 1.2: Topological Electrons and Photons

PIs: Fu, Soljačić

Topological physics enables a wide range of novel phenomena and devices. Many such concepts and devices could provide novel military functionalities. Moreover, the recent revolution in machine learning offers opportunities to transform topological and band structure research. Project 1.2 will investigate two important interrelated topology topics — topological optoelectronics, and machine learning for topology and band structure — under the guidance of Professors Soljačić and Fu, leaders in topological photonics, topological electronics, and machine learning, with long histories as successful collaborators.

Project 1.3: Chip Integrated, On-Demand, Scalable Single Photon Sources

PIs: Bawendi, Gopinath

Quantum information processing (QIP) has established itself as a central platform of 21st century technology. Quantum photonics is a major branch of QIP, promising the generation and manipulation of photonic qubits as carriers of quantum information. The

Bawendi and Gopinath groups aim to combine their unique capabilities in the areas of colloidal quantum dot emitters and DNA origami to solve fundamental challenges of existing systems. Project 1.3 aims to establish the first chip-integrated source of single and entangled photons based on colloidal emitters, and the first platform scalable to the needs of a technology ready for deployment.

SRA 2: Sciences of Materials for Extreme Environments

Project 2.1: Data-Driven Discovery and Design of New Superelastic Ceramics

PIs: Schuh, Radovitzky

Superelastic ceramics offer promise in Army blast/impact protection applications. Current superelastic ceramics with promising dissipative properties are essentially limited to zirconia. Previous ISN work by the Schuh and Radovitzky groups has thoroughly investigated zirconia superelastic ceramics and achieved key demonstrations including scale-up to cm-scale specimens in single crystals and granular packings. However, bulk polycrystalline superelastic ceramics would be an even more desirable form. Work on zirconia has revealed the key physics of this class of materials, and researchers are now able to predict the structures necessary to a polycrystalline superelastic condition. Project 2.1 will use the modern toolkits of materials discovery and design to identify promising new compositions, which will then be reduced to practice and validated.

Project 2.2: Designer Lightweight 3D Nanolattice Materials

PI: Portela

Previous ISN work by the Portela group has showcased the combined benefits of nano/microscale features and three-dimensional (3-D) material architectures to obtain extreme impact mitigation efficiency. Project 2.2 will leverage these results by designing, fabricating, and testing such materials in order to identify design principles for enhanced impact performance at different energetic regimes. Materials will be designed to maximize their dissipated impact energy per unit mass by harnessing shock compaction mechanisms and nanoscale size effects. Using a combination of experimental techniques and simulations, researchers will uncover guiding principles for the design of a new generation of ultra-lightweight impact-mitigating 3-D architected materials with deterministic design at the nano/microscale.

Project 2.3: Solution-Phase Synthesis of 2D Polymers

PI: Strano

Polymers that extend covalently in two dimensions have been long conceptualized but their synthesis has remained elusive. They promise a unique combination of the high mechanical strength with the low densities, synthetic processability, and composition control of one-dimensional polymers. The Strano research group previously demonstrated the first synthetic route to 2-D irreversible polycondensation directly in the solution phase, while Army collaborators have demonstrated that such materials can achieve previously unattainable levels of mechanical strength per mass and area.

Already achieved solution processing at preparative scales enables highly oriented, large-area free-standing films exhibiting exceptional 2-D elastic modulus (>50 GPa) and yield strength (>1.0 GPa). Project 2.3 will elucidate the first relationships between organic composition and key mechanical properties in various architectures for new types of lightweight, high strength materials.

Project 2.4: Long Nanofiber Reinforcement of Bulk Ceramics

PIs: Schuh, Wardle

Emerging military applications like hypersonics require the development of lightweight ceramic composites with enhanced thermal stability and shock resistance, necessitating high strength and fracture toughness at elevated temperatures. Bulk ceramics with enhanced fracture toughness and ductile failure behavior have been recently engineered via nanoporosity and nanofibers, but with processing and scale limitations. In Project 2.4, the Schuh and Wardle research groups will study a new platform for creating tough, strong long-nanofiber-reinforced bulk ceramics at extreme volume fractions and nanofiber lengths far beyond what is currently possible.

SRA 3: Energy Sciences

Project 3.1: Large Energy Density Photon Sources with Designer Emissivities

PIs: Celanovic, Fisher

Small-scale power sources (0.1 Watts – 100s of Watts) with extreme energy densities remain elusive. Power sources that significantly exceed 105 Wh/kg at millimeter scales could revolutionize remote sensing and data processing, small robotic platforms, unmanned vehicles, and more. With Project 3.1, the Celanovic and Fisher research groups will design and demonstrate an extreme energy density mesoscale radioisotope-fueled thermophotovoltaic (RTPV) power source that will take advantage of the up to six orders of magnitude larger energy density of certain radioisotopes compared to standard battery chemistries. They will develop an RTPV architecture using thin-film conformal thermophotovoltaic cells, highly reflective backside mirrors, extreme view-factor thermal cavities based on cylindrical coaxial architecture, and the first-of-its-kind conformal metallodielectric high-temperature photonic crystal selective emitter.

Project 3.2: Synthesis, Processing, & Structure-Property Relationships of High-Surface-Area Mesoporous Nanocomposites

PI: Macfarlane

The ability to manipulate material organization simultaneously at different length scales is critical to achieving novel physical and chemical characteristics while establishing fundamental understanding of the physics and chemistry concepts governing material behavior. Meso- and nanoporous materials are a key example of this need for structural control, as the amount of available surface area and pathways for molecule diffusion are directly controlled by the size, shape, and connectivity of pore structures across the nano- to macroscopic size regimes. An informative model system is silicon, which has an exceptional capacity to store lithium. A hierarchical mesoporous framework to encapsulate silicon nanoparticles would allow for study of fundamental processes involved in the charging and discharging of capacitors, such as diffusion, adsorption, and dynamic changes to internal structure. To gain insight into the structure-property relationships that determine the electricity storage and release, and other properties of materials, Project 3.2 will rationally design hierarchical architectures to construct these materials from the bottom up and then study their properties to gain scientific knowledge and for practical applications (e.g., energy storage, filtration and separation, and catalysis).

SRA 4: Devices and Materials with Advanced Functionalities

Project 4.1: Digital Fibers and Fused Novel Multifunctionality in Fabrics

PIs: Fink, Joannopoulos

Fabrics uniquely surround the warfighter, and are exposed to information from both inside and outside of the body, such as heartbeat, sweat composition, air quality, temperature, and sound. These signals could provide important insights on the soldier's physiological status and the environment if fabrics could sense, store, compute, infer, communicate, and act. Functional fibers are now setting the stage for computing fabrics. The objective of Project 4.1 is to explore the underpinnings of an operational fabric computer made entirely from fibers. The nanostructured fabric will fuse multimodal sensing, memory, processing, power, and communications, containing customized algorithms to sense the environment both internal and external to the Soldier, while being capable of extended autonomous operation for power-scarce and communication-denied environments. The culmination of this effort will be a field-programmable fabric system that can dynamically address mission-specific needs through software applications to enable contextualized understanding of physiological state, health, injury status, and threat detection to enhance situational awareness.

Project 4.2: Distributed Inference Based on 2-D Materials for Spectral Studies in the RF

PIs: Palacios, Kong

Two dimensional materials like graphene and molybdenum disulfide (MoS_2) have tremendous potential for smart surfaces providing unprecedented RF sensing and communication capabilities to DoD systems. When applied at large scale, these smart surfaces will generate an immense amount of data to be processed and acted upon, creating a significant interconnection/communication bottleneck. Project 4.2 will develop the basic science, materials, devices, and technologies needed to demonstrate two of the most important building blocks for future smart RF surfaces: high frequency electronic devices compatible with large area fabrication, and a distributed machine learning architecture to allow for real time local decision making (inference). The project will leverage the researchers' extensive expertise on MoS_2 devices and circuits to demonstrate the integration of GHz-class MoS_2 RF receivers and transmitters with MoS_2-based artificial synapses that enable the classification and prioritization of sensor data under almost-zero latency. These building blocks will be used to prototype a flexible smart surface capable of providing real time RF sensing.

Project 4.3: High-Definition Quantum-Limited Optical Bolometry

PI: Englund

Uncooled thermal imagers measure temperature changes via a temperature-dependent property of the sensitive element. However, state-of-the-art thermal imagers, such as VOx-based systems, are limited by electronic readout noise that precludes reaching the fundamental sensitivity. In this project, the Englund research group will focus on developing a new thermal imaging technology based on thermo-optic readout as an optical pre-amplification stage that allows system sensitivity at the fundamental limit of bolometer sensitivity. Building on the team's recent demonstration of thermal fluctuation-limited readout of a micron-scale optical microcavity and successful translation into 300 mm CMOS manufacturing, the ability to achieve quantum-limited thermal imaging with HD-4K resolution in a camera-sized, uncooled imaging platform is anticipated. Moreover, additional unprecedented capabilities, including hyperspectral imaging without significant thickness increase, ultrafast optical pre-processing, simultaneous imaging at multiple focal planes and of multiple regions of interest without moving parts, fully programmable image sampling at the nanosecond-scale, and readout bandwidth exceeding Tbit/second are all foreseen.

SRA 5: Soldier Medicine: Battlefield Care & Hazardous Substances Detection and Protection

Project 5.1: Enzyme-Encapsulation and Performance of Nucleic Acid Nanoparticles

PI: Bathe

Chemical countermeasures are crucial to 21st century military and civilian defense. While protective enzymes are available to neutralize a range of lethal compounds, molecular carriers that enable both their prophylactic use and their environmental dissemination are unavailable or severely limited. DNA nanotechnology offers the ability to program highly structured, nanometer-scale virus-like particles (VLPs) with controllable size, geometry, chemical composition, and biodegradation properties, using the principle of scaffolded DNA origami. VLPs can be used to encapsulate single or multiple distinct chemical warfare conversion enzymes with controlled copy numbers to enhance their enzymatic activity and stability. In Project 5.1, the Bathe research group explores principles of fabricating DNA origami VLP-encapsulated enzyme systems for countermeasures against chemical warfare agents. Activity and neutralization of these agents will be investigated in vitro and in vivo, as well as in models for environmental dissemination. This project will form the basis for novel countermeasures that may be deployed on the battlefield for warfighter protection from diverse chemical warfare agents, and might also be extended to include biological warfare agents.

Project 5.2: Dynamic Multi-Phase Emulsions

PIs: Kolle, Swager

Fluid multiphase emulsions and emulsion-derived solidified microstructures have proven beneficial for pathogen detection, responsive optical components, and adaptive light management. These emulsions register nanoscale chemical interactions via a response in their morphology and organization, which can be observed on the macro-scale, enabling highly sensitive and selective biochemical sensing. In Project 5.2, the Kolle and Swager research groups will leverage emulsion technology and expertise in surfactant and emulsion design, bio-chemical sensing, optics, and imaging to develop compact, field-deployable prototype devices for rapid pathogen detection, live/dead bacteria identification, and light-field imaging for bio-fluid diagnostics in remote, tech-limited settings, enabling new functionalities for the Soldier.

Project 5.3: Synthesis, Processing, and Properties of Nanoscale Platelet Mimicking and Hemoglobin Encapsulating Nanoparticles

PIs: Hammond, Olsen

Uncontrolled hemorrhage is a leading cause of death on the battlefield and for civilians under 45 years of age. Key treatment is fluid resuscitation; however, the use of clear fluids can decrease both the clotting and oxygen-carrying capacity of blood, critically impairing patient recovery. Project 5.3 will develop blood-like nanoparticles that can be added to standard IV fluids to impart clotting and oxygen-carrying capacity without the need to transport and store whole blood, providing a transformative advance in medical capability. The Hammond and Olsen research groups will apply a combination of biopolymers and protein-based materials to develop a formulation including oxygen-carrying nanoparticles that mimic red blood cells, platelet-like nanoparticles that can responsively clot in wounds, and recombinant and peptide-based mimetics of fibrin that can replace the diluted blood proteins to restore clotting function. These nanomaterials will be engineered to function synergistically with natural blood, working to support and reinforce the body's natural systems.

In addition to these core projects, the ISN supports projects funded through alternative funding methods such as Military Interdepartmental Purchase Requests (MIPRs), which allow U.S. military services and agencies to fund targeted research of special interest to them, and collaborative projects with MIT Lincoln Lab. Also, the ISN supports seed projects, allowing the ISN to respond swiftly to emerging needs and opportunities.

Funding

Sponsored ISN expenditures since 2002 exceed $240 million, with the majority of these funds having been obligated through contracts awarded by the U.S. Army Combat Capabilities Development Command (DEVCOM) Army Research Laboratory (ARL) Army Research Office.

The ISN continues efforts to expand its sources of funding in order to strengthen its research portfolio and augment its science and technology contributions for the Soldier and other U.S. warfighters.

Collaborations

Army

Army partners are vital to the ISN mission. They collaborate with the ISN on basic and applied research, provide guidance on the Soldier relevancy of ISN projects, and participate in transitioning. The ISN maintains strong relationships with many Army research organizations (e.g., DEVCOM research, development, and engineering centers, including DEVCOM ARL and DEVCOM Armaments Center).

Other DoD and U.S. Government

ISN research projects are relevant to the needs of various U.S. military and other government agencies. Historically, the ISN has enjoyed interactions with organizations ranging from the U.S. Air Force and Special Operations Command to the U.S. Food and Drug Administration. The ISN continues to seek out opportunities to perform S&T research in service of the Nation.

Industry and Other Organizations

Industry — large businesses to start-ups — is vital to transitioning ISN basic research results into products and scaling them for affordable manufacture in quantity. Furthermore, many non-commercial entities work to transition and develop technologies for the benefit of warfighters, first responders, and others. The ISN cultivates relationships with organizations that can help facilitate the technological maturation of fundamental research. The ISN plans to update its industry program to align with today's needs of companies interested in transitioning ISN research to serve the Soldier.

Transitioning

The ISN emphasizes fundamental research, but transitioning promising research outcomes is a crucial component of the ISN mission. The ISN works with the Army, industry, and MIT Lincoln Laboratory so that promising ISN innovations rapidly mature to benefit the Soldier.

Army civilian John McConville is a part of the ISN headquarters team, helping maximize the effectiveness with which ISN technologies progress from the laboratory to higher stages of development, with particular emphasis on bringing technologies to the U.S. military.

Since the ISN's founding, more than 400 U.S. patents have been awarded on intellectual property (IP) enabled by ISN research. ISN IP has been licensed for development or commercialization by more than 40 companies, including well-established firms and start-ups created specifically for the purpose of transitioning ISN IP.

A Small Sampling of ISN Research Accomplishments between July 1, 2022 and June 30, 2023

Ultrasound Sticker for Continuous Medical Imaging

A team led by Professor Xuanhe Zhao has developed a stamp-sized hydrogel-based "sticker" that functions as an ultrasound device and can provide continuous imaging for 48 hours. The small device features strong adhesion and can supply clear, high-definition images of organs and tissues as patients perform regular activities. Although the present iteration of the device requires a physical connection to additional equipment in order to translate data into images, efforts are underway to add wireless capabilities. A paper detailing this research has been published in *Science*, and it was the subject of an MIT News article.

Low-Hysteresis Shape-Memory Ceramics

A team led by Professor Chris Schuh, by combining techniques including computational thermodynamics, phase transformation physics, crystallographic calculations, and machine learning, has developed a new shape-memory ceramic material with record low hysteresis — approximately an order of magnitude better than common shape-memory ceramics and five times lower than the previous best such materials — putting it into the same hysteresis range as common metallic shape-memory materials. A paper detailing this research has been published in *Nature*, and it was the subject of an MIT News article.

Tool Designs Nanomaterials that Conduct Heat in Specified Ways

ISN Research Scientist Giuseppe Romano, working with Professor Steven Johnson, has developed an algorithm and software system that automatically designs nanoscale materials to conduct heat in a specified manner, such as channeling heat in only one direction. This new tool may help lead to self-cooling computer chips and advanced thermoelectric materials. A paper detailing this research has been published in *Structural and Multidisciplinary Optimization*, and it was the subject of an MIT News article.

Technique May Lead to Bulk Synthesis of Hexagonal Boron Nitride Nanotubes

A new synthesis technique developed by a team including Professor Brian Wardle may lead to the practical bulk fabrication of hexagonal boron nitride (hBN) nanotubes. Also known as “white graphene,” hBN graphene can withstand higher temperatures than its carbon-based namesake, is electrically insulating rather than conducting, and is optically transparent, making it potentially useful in heat-resistant composites, high-strength windows, sensing platforms, and electronic devices. A paper detailing this research has been published in *ACS Nano*, and it was the subject of an MIT News article.

Low-cost THz Camera is Polarization Sensitive in Real-time

A team featuring Professors Vladimir Bulovic, Moungi Bawendi, and Keith Nelson has developed a fast, sensitive, low-cost terahertz camera that operates at room temperature and pressure and can capture information on the polarization of the THz waves in real-time. Work to improve the already impressive results, particularly though further miniaturization, continues, with an eye toward potential application in fields ranging from materials inspection and quality control to security scanning to astrophysics. A paper detailing this research has been published in *Nature Nanotechnology*, and it was the subject of an MIT News article.

Method Results in 100x Increase in Electron-Triggered Light Emission

A team led by Professors John Joannopoulos and Marin Soljačić and including ISN Principal Research Scientist Steven Kooi has developed an innovative method for strengthening interactions between photons and electrons, producing a 100-fold increase in light emission from Smith-Purcell radiation. The method is tunable to emit light at a wide range of wavelengths including terahertz, ultraviolet, and X-rays that are otherwise challenging to generate efficiently. This advance could ultimately have broad commercial and research applications — from radiotherapy to quantum computing to some functions currently available only through gigantic facilities like the Large Hadron Collider. A paper detailing this research has been published in *Nature*, and it was the subject of an MIT News article.

Two-component, Systemically Injectable Hemostat

Professors Bradley Olsen and Paula Hammond led a team that has developed a two-component, systemically injectable hemostat for the treatment of internal bleeding. The injected materials migrate to the potentially unseen or unidentified site of internal bleeding and there begin to arrest bleeding through primary and secondary hemostasis — platelet plug formation and fibrinogen clot formation. This system significantly improved survival in a mouse model when compared to hemostasis using nanoparticles only. Future work is expected to include research on imaging the hemostat materials in vivo in order to quickly identify hidden wound sites for faster additional treatment. A paper detailing this research has been published in *Advanced Healthcare Materials*, and it was the subject of an MIT News article.

Growing Atomically Thin Transistors 8-inch Silicon Wafers

A team led by Professors Jing Kong and Tomás Palacios, working with researchers from MIT Lincoln Laboratory and elsewhere, has developed a new low-temperature process to rapidly grow the 2-D semiconductor transistor material molybdenum disulfide directly on top of a silicon CMOS wafer without damaging the silicon or other chip materials. Each about three atoms thick, the transistors could be stacked to create more powerful electronic chips. This work is an important advance toward enabling fabrication of 3-D integrated circuits with much higher transistor densities and far greater power for computer and other electronic chip applications. A paper detailing this research was published in *Nature Nanotechnology*, and it was the subject of an MIT News article.

Fibers That Monitor and Manipulate the Brain–Gut Communications Network

Leveraging ISN-developed technologies from Professors Yoel Fink and John Joannopoulos, a multi-university team working with the NEC Corporation has developed a means to monitor and manipulate the communications network linking the brain to the gut. Exploring the use of thermally drawn, multimaterial, multifunctional fibers as sensors for these communications links, the fibers also featured lights for optogenetic stimulation that were able to prompt the release of various hormones and neurotransmitters. Eventually, these techniques and technologies could help with a number of neurological disorders that are likely linked to brain-gut communications. A paper detailing this research was published in *Nature Biotechnology*, and it was the subject of an MIT News article.

Outreach Activities

Visits and Meetings

Each year the ISN hosts a large number of prominent visitors. Although virtual meetings through Zoom, Microsoft Teams, and similar technology solutions remain common, following a dramatic slowdown in visits due to COVID-related restrictions, the ISN has seen an impressive return to form over the past year.

Notably, in the past year, the ISN has hosted Japanese State Minister for Cabinet Affairs Keitaro Ohno, Chief of the U.S. National Guard Bureau Gen. Daniel Hokanson, Executive Vice President of the University of Tokyo Prof. Toshiya Watanabe, and Chief

Technology Officer of the Israeli Ministry of Defense Dr. Gal Harari. Additionally, the ISN briefed Chief Science Advisor to the Ministry of Defence of the United Kingdom and Oxford professor Dame Angela McLean during her MIT visit.

Contributions to the MIT Community

The ISN facility has an active roster of approximately 300 users, including MIT personnel, Army, and other visiting researchers, who are trained to utilize ISN equipment and facilities, not counting those who are authorized to access ISN office, collaboration, and meeting spaces at a roughly 40,000 ft^2 dedicated installation at Technology Square in the northeast segment of MIT campus.

MIT users have access to ISN facilities, including laboratories, computer clusters, and advanced instrumentation. ISN equipment available to qualified MIT users includes a laser scanning confocal microscope, an atomic layer deposition system, an X-ray tomography system, and a field emission scanning electron. In the past year, enabled by a large financial award from the Army, the ISN has acquired several instruments that are the first of their kind at MIT or even in Greater Boston, including:

1. A Delmic SPARC Spectral cathodoluminescence (CL) detector system providing wavelength, angle, and polarization-resolved optical characterization from the UV to the near-IR is being added to a Zeiss Sigma-300 Field Emission SEM. This detector opens new areas of characterization of nanophotonic structures, optoelectronic, semiconductor, and geological materials.

2. A Nanofilm EP4 – Imaging Spectroscopic Ellipsometer by Accurion (spectral range: 250–1700 nm; lateral ellipsometric resolution: ≥1 μm). This instrument’s extreme lateral resolution is a huge upgrade over previous ellipsometers and is a new advance in the field. The ability to obtain high-quality ellipsometric data from small and/or patterned samples at high spatial resolution is a powerful new tool for the ISN and MIT.

3. A confocal Raman microscope with a UV laser light source and the latest advances in Raman microscopy, adding a 325 nm laser light source to more commonly available laser wavelengths of 532, 633, and 785 nm. Advances in detector and optics technology have vastly reduced the time for spectral mapping experiments and enable measurement of signals much closer to the excitation laser frequency. This is the first Raman system at MIT to include a UV excitation laser; it will be an important tool for researchers working with 2D materials.

4. An Asylum Research Jupiter Atomic Force Microscope (AFM) with the latest high-performance AFM features including fast high-resolution AFM imaging and high-precision nanomechanical measurement capabilities. This system will provide updated AFM capabilities and bandwidth to ISN and other MIT researchers who do not require MIT.nano’s clean room.

ISN leadership engages with the broader MIT community through participation in Institute committees including, historically, the Lincoln Laboratory-Campus Interaction Committee, the MIT-DoD Engagement Group, and the MIT Committee to Evaluate the Innovation Deficit. In the past year, ISN Associate Director Raúl Radovitzky was a member of the COVID Management Team and the School of Engineering Commencement Committee, chaired the Committee on Student Life and, as McCormick Hall's head of house, was the Undergraduate Heads of House Convener.

Special Programs

In Spring 2022, the ISN was named recipient of a generous endowed gift from MIT alumnus Aneal Krishnan '02, who designated his donation to the support of MIT Reserve Officers' Training Corps (ROTC) cadets participating in ISN research through the Undergraduate Research Opportunities Program (UROP). Following significant planning and multiple rewarding discussions with Mr. Krishnan and MAJ Tom Allen, Professor of Military Science and commander of MIT's Paul Revere Army ROTC Battalion, the ISN will fund its first two participating UROP students working on ISN research projects in Fall 2023.

Future Plans

The ISN mission remains relevant to the needs of Soldiers, other U.S. warfighters, first responders, and the Nation. The ISN will build and strengthen partnerships with the Army, other U.S. services and agencies, industry, and MIT Lincoln Laboratory. The ISN will continue to enable innovative capabilities to aid military and civilian personnel in the completion of difficult and high risk activities.

John D. Joannopoulos
Director, Institute for Soldier Nanotechnologies
Francis Wright Davis Professor of Physics
Member, National Academy of Sciences
Member, American Academy of Arts & Sciences