The US Army's Institute for Soldier Nanotechnologies at MIT
The mission of the ISN is to help the US Army and other services dramatically improve the survivability and efficacy of the Soldier, as well as other warfighters, platforms, and devices. By working at and extending the frontiers of nanotechnology through fundamental research, and by collaborating and transitioning with our Army and industry partners, our goal is to make the Soldier not only safer but also more effective and more comfortable through lighter weight clothing and equipage.

There is an extremely important aspect of nanotechnology that goes beyond just making things small: the intrinsic properties of matter (e.g., dielectric, mechanical, transport) become size dependent below a critical length-scale of a few hundred nanometers. This provides opportunities for the discovery of new materials with phenomena and properties that are otherwise unattainable in nature.

Transitioning discoveries is also vital, and MIT has a long history and accomplished culture of entrepreneurship. Faculty, students, and research staff strive to reap the fruits of basic research and rapidly deploy them to the customer. In this regard, the focus of the ISN on the Soldier has many dual-use applications to first responders, law enforcement officers, firefighters, and the civilian community at large.

John D. Joannopoulos
Director, Institute for Soldier Nanotechnologies
Francis Wright Davis Professor of Physics, Massachusetts Institute of Technology
Member, National Academy of Sciences
Team members collaborate on basic research to create new materials, devices, processes, and systems, and on applied research to transition promising results toward practical products useful to Soldiers and other warfighters. Army members of Team ISN also give guidance on Soldier protection and survivability needs, and the relevancy of research proposed to address these needs. Army and industry partners share their expertise on how to convert promising outcomes of fundamental research into practical products that work in harmony with other Soldier technologies, and which can be manufactured affordably in the quantities needed by our Soldiers. Moreover, these collaborations help identify dual-use applications for ISN-derived technologies for firefighters, police officers, other first responders, and, indeed, the civilian community at large.

Mission

The ISN mission is to help the US Army and other US military services dramatically improve the protection, survivability and other capabilities of the Soldier, other US warfighters, and their platforms and systems, through basic research on nanotechnology and by transitioning promising outcomes of that research in partnership with the Army, other US military services, and industrial companies. This mission includes decreasing the weight that Soldiers carry, improving blast and ballistic protection, creating new methods of detecting and detoxifying chemical and biological analytes, providing physiological monitoring and automated medical intervention, and enhancing situational awareness.

To carry out this mission, the ISN has developed a diverse set of core S&T competencies strengthened by an operating model that emphasizes cutting edge research coupled with rapid transitioning through Army and industry partners, as well as startup companies fostered by MIT’s strong culture of entrepreneurship.

History

The ISN is an Army-supported University-Affiliated Research Center (UARC), and a product of the Army’s vision to explore the potential power of nanotechnology to enable unprecedented advances in Soldier protection and survivability. The ISN was designed to collaborate on basic and early applied research with Army and industry partners, and enable both to transition promising results. On March 12, 2002, the Army announced that it had selected MIT’s proposal from a host of submissions by some of the nation’s best colleges and universities, and the ISN was officially founded two days later on March 14, 2002. The official opening ceremony of the ISN dedicated facility was held on May 22, 2003.
Challenges

Soldiers and other members of the US Armed Forces face many challenges in performing their diverse missions. Military threats include blast and ballistic impacts, chemical and biological weapons, radiological and other hazardous materials, directed energy weapons, nuclear devices, and electronic and cyber warfare. Beyond these threats, warfighters must function in varied climates and weather conditions, and in environments ranging from remote wilderness to densely populated cities. These conditions and venues present risks of personal injury and illness, significantly exacerbating already complex military challenges. Clothing, equipage, and platforms must provide high functionality while minimizing their size, weight, power demand, and cost (SWAP-C).

The breadth and depth of these challenges is documented in the following Army Modernization Priorities expected to be major focus areas of the new Army Futures Command:

- Long Range Precision Fires
- Next Generation Combat Vehicle
- Future Vertical Lift
- Air and Missile Defense
- Network/Command, Control, Communications & Intelligence
- Assured Positioning, Navigation, and Timing
- Synthetic Training Environment
- Soldier Lethality

Nanotechnology for the Soldier

Nanotechnology can enable cutting-edge technologies that provide potentially transformational capabilities by harnessing the size dependence of physical, optical, electrical, and chemical phenomena that occur at tiny length scales. The result can be new materials, processes, devices, and systems that provide unprecedented advances in technologies to provide protection and other capabilities to the warfighter and the warfighter’s platforms.

The nanoscale range is truly minute — the diameter of a single human hair is roughly 80,000 nm — and size-related behavior opens up potentially paradigm shifting opportunities. Nanoscale materials and devices, either directly or as components of larger products, allow for multiple capabilities in tiny, lightweight building blocks. Therefore, nanotechnology is ideally suited to enhance functionality at reduced weight, a key driver of the ISN Mission. ISN researchers have demonstrated that a wide variety of nanomaterials can be synthesized and integrated into prototype devices and fabrics. Theoretical and computational efforts at the ISN complement experimental research programs in order to understand and optimize material properties. Moreover, nanotechnology is inherently interdisciplinary, bringing together areas of science that are historically very different, allowing innovators to capitalize on the unique features of each.

For example, ISN scientists are combining the traditionally low cost and high production volumes of textiles manufacturing with the exquisitely customized electronic properties typically achieved via the expensive processing of semi-conductors. The potential impact is unique optoelectronic fibers for full-body coverage of the Soldier, buildings, and vehicles to detect heat, light and sound, made possible by the ability to produce these fibers at the speeds, costs, and quantities expected from mass production of textiles.
Core Competencies

Science and Technology

- **Advanced Materials with Novel Mechanical Properties** for Weight Reduction, Protection, Lethality, and Damage Detection
- **Dynamic, High Fidelity 3D Modeling and Simulation** of Durability, Fracture, and Failure of Materials, Platforms, and Structures under Blast and Ballistic Impacts
- **Multimaterial Fiber and Fabric Devices** for IFF, Communications, Detection and Emission of Heat, Light, and Sound, and for Energy Generation and Storage
- **Network Science** – Localization and Navigation, Interference Exploitation, Secrecy, Collaborative Multi-target Tracking, LPI/LPD, Satellite Communications Systems
- **Neuromorphic, Optical Deep Learning Computing Architectures** for Ultrafast, Ultralow Power Calculations
- **Next Generation “Electronics”** – 2D Systems, Optoelectronics, Photonic Integrated Circuits, Unconventional Information Carriers
- **Novel Topological Phenomena** (Electronic & Photonic) for Communications, Detection, and Signal Processing Technologies
- **Portable, Widely Tunable Electromagnetic Radiation Sources** from Terahertz to X-ray
- **Sensing Technology for Full Spectrum Situational Awareness** – Detection, Imaging, and Ranging of Chemical, Biological, Radiological, Nuclear, and Explosives Threats, and of Stationary and Mobile Targets
Operating Model

• **Basic (6.1) Research** in the Physical, Biological, and Information Sciences Coupled with Engineering to Enable Novel Technologies for US Military and National Security Applications

• **Applied (6.2 and 6.3) Research** on the MIT Campus to Facilitate Technology Maturation

• **Seed Funding** to Fast-Track Exploration of New Research Ideas

• **MIT R&D Infrastructure** - The Ability to Rapidly Engage Experts from Across the MIT Campus and MIT Lincoln Laboratory to Provide a Critical Mass of Talent in Response to New and Emerging S&T Challenges

• **Rapid Transitioning** of the Promising Results of On-Campus Research by Partnering with the Army, Other US Military Services, and Industrial Companies

• **Strong Focus on Substantive, Symbiotic Collaborations** with the Army, Other US Military Services, Industry, and MIT Lincoln Laboratory to Discover and Advance Novel Technology Solutions for US Defense and Homeland Security Needs

• **MIT Ethos of Innovation and Defense R&D** - Major Contributor to and Beneficiary of the MIT Culture of Entrepreneurship and the MIT Defense Research Ecosystem

• **Supporting Sensitive R&D** - Information Firewalls Provided by Off-Campus Partners Enable the ISN to Perform On-Campus, Non-Classified Research at MIT in direct Support of Extramural Classified Studies
People

Headquarters Team

Director
Prof. John D. Joannopoulos
Francis Wright Davis Professor of Physics

Associate Director
Prof. Raúl A. Radovitzky
Professor of Aeronautics and Astronautics

Executive Director
Dr. William A. Peters

Outreach and Communications Director
Franklin E.W. Hadley

Assistant Director of Administration and Finance
Josh Freedman

Laboratory and Facilities Manager
Amy Tatem-Bannister

Principal Research Scientist
Dr. Ivan Celanovic

Principal Research Scientist
Dr. Steven Kooi

Research Specialist/SDC Coordinator
Kurt Keville

Research Specialist
Bill DiNatale

Research Support Associate
Donna Johnson

Finance Assistant
Maureen Caulfield

Executive Administrative Assistant
Marlisha McDaniels

Faculty

Each year, between 25 and 50 MIT faculty members participate in ISN research. These faculty members hail from 14 academic departments and centers, making the ISN one of the most scientifically diverse research organizations at MIT.

Post-Docs and Students

The ISN provides an intellectual home to some of the world’s most talented post-doctoral associates and graduate students. More than 100 post-docs and students participate actively on ISN projects. In total, nearly 500 MIT researchers have access to utilize the ISN’s extensive equipment inventory and laboratory space.

Army Visiting Scientists

While the majority of people working at the ISN are faculty, post doctoral associates, students, and staff of MIT, the ISN is also pleased to host a number of visiting scientists and researchers from the US Army science and technology communities. Current appointments at the ISN include:

Dr. Yassine Ait-El-Aoud, NSRDEC
Dr. Stephen Bartolucci, Jr., ARDEC
Dr. Christopher Doona, NSRDEC
Dr. Melissa Flagg, ARL
Dr. Alex Hsieh, ARL
Dr. Robert Jensen, ARL
Dr. Joshua Maurer, ARDEC
Dr. Charlene Mello, NSRDEC
Dr. Richard Osgood III, NSRDEC
Dr. Bora Yoon, ORISE - NSRDEC

Facilities

Headquarters

The ISN maintains over 40,000 square feet of space in a dedicated facility located in Cambridge’s Technology Square. Approximately 500 registered users from across MIT have access to ISN facilities that include wet and dry labs, computer clusters, and mechanical testing and research instrumentation, including equipment for low- and high-rate mechanical characterization of the dynamic response of materials, electron microscopy, and femtosecond laser spectroscopy.
Collaborators

**Industry**

Industry partners are critical to the ISN Mission, helping turn innovative results of basic research into real products and scale them up for affordable manufacture in the quantities needed by end users. ISN industry partners have included:

- Consortia for Improving Medicine with Innovation & Technology (CIMIT)
- Dow Corning
- DuPont
- FLIR Systems
- General Atomics
- W.L. Gore and Associates
- Honeywell
- JEOL USA
- Lockheed Martin
- Mine Safety Appliances
- Nano–C
- Nike
- Northrop Grumman
- QD Vision
- QinetiQ North America
- Raytheon
- Total American Services
- Triton Systems
- Veloxint
- VF Corporation
- Xtalic
- Zyvex

**Army**

Army research partners are vital to the ISN Mission. They collaborate on basic and applied research, provide guidance on the Soldier relevancy of ISN projects, and participate in transitioning (i.e., technological maturation and scale-up of the outcomes of ISN basic research). The ISN has had substantial interactions with many Army science and technology laboratories and centers, including:

- US Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC)
- US Army Armament Research, Development, and Engineering Center (ARDEC)
- Army Research Laboratory (ARL)
- US Army Communication-Electronics, Research, Development and Engineering Center (CERDEC)
- US Army Edgewood Chemical Biological Center (ECBC)
- Madigan Army Medical Center
- US Army Natick Soldier Research, Development and Engineering Center (NSRDEC)
- Night Vision and Electronic Sensors Directorate (NVESD)
- Program Executive Office - Soldier (PEO-Soldier)
- US Army Tank Automotive Research, Development, and Engineering Center (TARDEC)
- US Army Corps of Engineers
- US Army Medical Research Institute of Infectious Diseases (USAMRIID)
- US Army Research Institute of Environmental Medicine (USARIEM)
- Walter Reed Army Institute of Research (WRAIR)

**Government, DoD, Academia**

- Camp Roberts
- Deployed Warfighter Protection Program
- National Intrepid Center of Excellence
- Naval Postgraduate School
- Naval Sea Systems Command
- US Air Force
- US Special Operations Command
- Walter Reed National Military Medical Center
- US Department of Agriculture
- US Food and Drug Administration
- MIT Lincoln Laboratory
- Institute for Collaborative Biotechnologies
- Howard University
- City College of New York
ISN research is organized into three Strategic Research Areas (SRAs), representing the most fundamental subject areas for scientific inquiry at the ISN. SRAs are designed to address broad strategic challenges facing the Soldier, and are subdivided into specific Projects.

**Strategic Research Area 1: Soldier Protection, Battlefield Care, and Sensing**

SRA-1 focuses on studies to develop lighter weight, stronger materials to protect the Soldier and Soldier-augmenting platforms and systems from mechanical damage owing to blast waves, ballistic impacts, and mechanical vibrations, using various mechanisms of energy absorption including phase transitions and material deformation. Specific materials of interest include molecular composites, organic polymers, superelastic nanocrystalline metal alloys and ultra-high strength ceramic formulations. This SRA includes research to elucidate how materials fail under high rate mechanical loads. This work provides new understanding of how to design and make new types of lightweight, durable, high strength materials, on how to reliably test protective materials under simulated battlefield conditions and how to interpret the results of these tests to obtain further insights to improve protective materials. One project examines the use of packed granular particles of shape memory ceramic materials to dissipate energy through inter-particle friction and intra-particle martensitic phase transformations with interest in applications to vibrational damping. Another project features basic research on three different nanomaterials to arrest bleeding in battlefield wounds that cannot be treated by traditional methods of macro-compression, including use of injectable hemostats to counter the vexing problem of internal bleeding. Another project focuses on novel means to protect the Soldier against infections. The approach is to safely intervene in the human immune system through the design of novel lymphoid- and leukocyte-targeting nanomaterials that concentrate adjuvant compounds and immunomodulators in immune cell populations to respectively enhance prophylactic vaccines and anti-microbial therapies.

- Project 1.1: Advanced Multiscale Methods for Modeling of Fracture in Novel Nanomaterials
- Project 1.2: Shock Mitigating and Reinforcing Molecular Nanocomposites
- Project 1.3: Design & Testing of Polymers for Improved Soldier Protection
- Project 1.4: Superelastic Granular Materials for Impact Absorption
- Project 1.5: Rapid Hemostasis for the Treatment of Incompressible Wounds
- Project 1.6: Empowering Future Vaccines & Immunotherapies with Nanotechnology-Based Adjuvants
Strategic Research Area 2: Augmenting Situational Awareness

SRA-2 concentrates on providing the Soldier and Soldier platforms with the next level of capabilities for secure communications, multi-faceted situational cognition and visualization, and invulnerability to enemy detection and potentially for some cases, immunity to enemy EMP and spoofing technologies. The approach is an in depth examination of diverse segments of the EM spectrum currently under-exploited owing to inadequate scientific understanding of the basic physics of novel electronic, optical, and electromagnetic phenomena, or the unavailability of efficacious materials and devices to capitalize on recent progress in this understanding. For example, one project performs experimental and modeling studies to develop materials and devices that will bring hyperspectral resolution to thermal- and mid-IR imagers based on graphene and thereby produce a fully functional hyperspectral focal plane array. To tackle a longer wavelength domain a different project focuses on providing fundamental understanding of field-enhanced electroluminescence in quantum dots to enable up-conversion of LWIR and THz radiation to emissions in the visible. A third project features systematic studies of nanoplasmonic phenomena that enable non-intuitive shrinking of light waves with potential applications to compact radiation sources from THz to X-rays, secure communications, and more powerful obfuscant particles. Another project seeks to synthesize novel mechano-optic, electro-optic and thermo-optic fibers that can be used to enable high bandwidth communications and reflectivity management of Soldier clothing and platforms. Finally, SRA-2 includes in situ studies of electrode-electrolyte interfaces of an operating solid-state lithium ion battery to gain new fundamental understanding of the battery chemistry to improve the power density and shelf life of these power sources used in diverse equipment for Soldier communications, ISR, etc.

- Project 2.1: Uncovering Chemical Stability & Charge Transfer Mechanisms at Electrode-Electrolyte Interfaces
- Project 2.2: Mid- & LW-Infrared Detector Arrays on Flexible Substrates
- Project 2.3: Room Temperature LWIR-THz Detection via E-Field Enhancement-Induced Quantum Dot Upconversion
- Project 2.4: Particulate Fluid Fiber Processing for Fabric Communications
- Project 2.5: Nano-Plasmonics for Soldier Applications

Strategic Research Area 3: Transformational Nano-Optoelectronic Soldier Capabilities

SRA-3 primarily focuses on understanding fundamental optical, electronic and transport/reaction phenomena in nanostructured materials and learning how to apply these phenomena to enable major advances in portable power, communications, signal processing and detection. One project seeks to harness non-Planck thermal radiation spectra from photonic crystal surfaces and near-field surface emission phenomena to provide compact thermophotovoltaic (TPV) and TPV/thermoelectric solid state electric power generators in the 1-100 W range. Another project studies fundamental mechanisms of photon transport in 3D and 2D materials to enable 2D optical integrated circuits for LIDARs, displays, communications and ultra-fast architectures for neuromorphic, optical deep learning computing architectures. A third team capitalizes on unusual optical resonances in condensed matter arising from Weyl points, other exceptional points, and stable topological bound states within the continuum to advance the state-of-the-art in high power IR and THz lasers for applications to amplifiers, spatial modulators, optical sensing and optical image processing. Another project combines first principles and analytical studies with novel device design and materials synthesis to explore use of topological phenomena (both photonic and electronic) in novel communications, signal detection and signal processing. The fifth project works to establish the basic principles to eventuate multi-scale 3D printing of high functionality fiber devices through synergistic integration of thermal fiber device drawing with 3D printing of the material fed to the draw tower. Objectives of this project are to enable: (a) recursive-manufacturing processes able to introduce nanoscale features into macroscale products in a highly controlled manner; (b) by understanding fluid instability growth rate, new paradigms for creating solid state multimaterial “inks” for conversion into or functionalization of fibers; and (c) the capability to create non-equilibrium micro- and nanostructured multi-material solids of unusual shapes (e.g. Janus and beach ball-like spherical particles) within fibers through capillary breakup of multimaterial fiber cores.

- Project 3.1: Solid State Power Generation at Millimeter Scales
- Project 3.2: Photonic Integrated Circuits for LIDARs, Displays & Low-Power Computing
- Project 3.3: Nanophotonics Enhanced Systems for the Soldier
- Project 3.4: Applications of Novel Topological Phenomena
- Project 3.5: Novel Multimaterial Inks for Multiscale 3D Device Printing
Selected Research Accomplishments

Quantum Dot-Enabled Hyperspectral Imaging:
A wealth of valuable information can be acquired by imaging outside the visible range of wavelengths. Hyperspectral imaging, the goal of which is to gather data from across the electromagnetic spectrum, has applications in fields including medicine, agriculture, astronomy, chemistry, and surveillance. Work by ISN faculty with colleagues at Raytheon and CERDEC’s Night Vision and Electronic Sensors Directorate has advanced the science and technology of hyperspectral imaging by replacing traditional optics - lenses and filters in complex configuration and precise alignment - with quantum dots capable of performing the same function at reduced size, weight, and expense.

Refractory Metal Alloys for Lightweight Protective Materials:
Thanks to ISN faculty and startup Veloxint, working with ARL and ARDEC, advances in powder metallurgy have allowed for the creation of highly tailored nanocrystalline refractory metal alloys that combine unprecedented strength - in some cases several times that of traditional alloys - with easy, efficient processability and even 3D printability. Despite the daunting weight of some alloys, these advances have led to the potential for reduced weight protection due to the fact that less material can achieve the same standard of security.

UV Visualization on IR Imagers:
In recent decades, imaging outside the visible spectrum has become an increasingly important military capability. Infrared goggles have become a standard part of the Soldier’s toolkit, allowing enhanced visibility in darkness. Similarly, UV tagging is useful for covertly identifying objects, locations, and individuals. Now, advances by ISN faculty and colleagues at Raytheon and ARL have the potential to combine these two capabilities in one device. Quantum dots have been developed that when applied to a focal plane array downshift from UV to IR, allowing a UV image to be viewed on an IR device. Additionally, the possibility of modulating the incoming UV signal is being explored, adding the ability to perform line-of-sight communications and information transmission in the ultraviolet regime.
**Tough and Strong Nanoscale Fibers:**
Working with NSRDEC scientists, ISN-affiliated MIT faculty have developed a new process to produce nano-diameter scale fibers that are remarkably strong and tough. The new process avoids many of the trade-offs of previous production methods, which would produce strength at the expense of ductility and vice versa. Inexpensive and easy to produce, these new fibers could lead to the development of improved body armors and composite materials.

**Nanostructured Shape Memory Alloys:**
Based on a bamboo-like oligocrystalline nanostructure pioneered by ISN researchers working with ARDEC, ISN-faculty startup Kinalco’s unique copper-based shape memory alloys (SMAs) boast extreme performance but come at a substantially reduced cost compared to the currently standard NiTi-based SMAs. They offer ultra-high dampening; excellent fatigue life, conductivity, and thermal actuation; they can be electrically actuated; and they can be soldered and welded. Kinalco’s SMAs are in development for a number of civilian and military applications, including cabling, actuators, orthopedics, electronic connectors, and even clothing.

**Optoelectronic Fiber Devices:**
Despite regular changes to the Soldier’s uniform intended to increase comfort, enhance ergonomic functionality, and make camouflage patterns more appropriate to the operational environment, adding electronic, optical, or sensory capabilities has long required the addition of external devices. In a radical advance to fiber and fabric technology, ISN researchers have devised and manufactured a variety of multifunctional fibers - fibers that are comprised of the fundamental ingredients of optoelectronic devices - that could one day be incorporated into garments and other fiber constructs. This ISN science was deemed so promising that it formed the basis for Advanced Functional Fabrics of America (AFFOA). This new DoD Manufacturing Innovation Institute is part of the Manufacturing USA network and counts frequent ISN partner Natick Soldier Systems Center as a founding member.
Fluid-like Electron Flow:
An ISN-affiliated faculty member, in collaboration with investigators at the Weisman Institute of Science, has devised a way to demonstrate viscous behavior of electrons in sheets of graphene. Previously considered impossible, this fluid-like behavior of electrons leads to “eddies” and “whirlpools” of current, and could result in unforeseen possibilities in sensing technology.

CVD-Enabled Wires for Advanced Microchip Design:
Over the past several decades, increases to the speed and computational power of microchips have become expected, as the capabilities of today’s smartphones dwarf those of yesterday’s mainframes. Recently, however, chip manufacturers have begun to approach fundamental limits to the size of essential connective wires. Now, a process developed by ISN faculty in collaboration with scientists at the University of Chicago and Argonne National Laboratory that combines standard photolithography with a new chemical vapor deposition-based technique not only allows for the fabrication of smaller, denser wires but also adds the potential for novel complex architectures and patterns.

New Test Array Reveals that PUU Polymer Strengthens on Impact:
A collaborative team of ISN and ARL scientists, utilizing a unique experimental setup, discovered that high performance polymers made of poly(urethane urea) (PUUs) display hyperelastic behavior when impacted by silica microparticles at extremely high speed. The hyperelastic response occurs when the material is significantly deformed - compressed to half of its original thickness - across a very short amount of time, on the order of 1/100,000,000 of a second. Interestingly, the PUUs also show signs of rebounding from the deformation, unlike the response seen in other materials like cross-linked polydimethylsiloxane elastomers and polycarbonates. The researchers hope to use these discoveries in monolithic polymers to help design advanced composites for future iterations of the US Army’s combat helmet as well as face, body, and extremity protection, and even civilian gear such as athletic equipment.
Understanding Impact-Bonding of Metals:
ISN-affiliated MIT professors have collaborated on two different papers related to their work to better understand the mechanics of sprayed metal impacting a surface. The first paper details a revolutionary means of imaging the team’s experiments at high speed, while the second could affect future 3D printing and coating technologies.

Implantable Biosensor Allowing for Real-time Monitoring and Adjustment of Cancer Therapies:
While modern medicine offers a variety of treatment options for battling cancer, it lacks a way to monitor the effectiveness of those options in real-time. An ISN-affiliated MIT faculty member, working with USARIEM, has developed an implantable sensor that can continuously, wirelessly send data to clinicians, allowing them to adjust treatment in order to maximize efficiency while minimizing adverse side-effects.

A Colloidal Quantum Dot Spectrometer:
Optical spectrometers are fundamental tools for materials analysis across many scientific fields. Challenges exist, however, in making these devices small, simple, and inexpensive. ISN faculty have devised a possible solution to these challenges. By using a planar array of quantum dots, the device obviates the need for complex optics and multiple filters, allowing different spectra to be distinguished using a single filter and a single detector.
Janus Emulsions for Food Safety Testing:
By utilizing Janus emulsions - tiny droplets composed of two hemispheres of different materials - an ISN faculty member has developed a new sensing system for food-borne pathogens such as *e. coli*. The particular Janus droplets used have one half that binds to bacteria, creating a clear visual signal that can be detected by a cell phone, other imager, or the naked eye.

“Motors” Driven by Light:
A team led by an ISN-affiliated MIT faculty member has predicted through simulation a Janus particle that, unlike previously available Janus particles, can be manipulated with non-specialized light rather than heavily process laser light. The team has begun working to experimentally validate their theories. Ultimately, this work could have applications in a number of areas, including the medical field.

Optical Neural Circuits:
ISN-affiliated MIT faculty members have created a programmable nanophotonic processor that may provide a dramatic advancement in so-called “deep learning” computer systems. By utilizing optical circuits rather than traditional electronics, researchers predict that “[this] chip, once you tune it, can carry out matrix multiplication with, in principle, zero energy, almost instantly.”
A New Way to Generate X-rays:
ISN researchers have led a team in predicting a new way to create x-rays by bombarding graphene with photons, creating plasmons (discrete oscillations in surface electron density). The plasmons, in turn, could be used to generate pulses of radiation ranging from infrared to x-ray wavelengths. These systems could be used to create chip-based UV light sources and high-powered, and extremely accurate, bench-top x-ray devices.

The Experimental Observation of Weyl Points:
Despite their prediction by noted physicist and mathematician Hermann Weyl in 1929, building on earlier work by English physicist Paul Dirac, “Weyl points” – massless subatomic particles - escaped observation for some 86 years. In early 2015, a team of scientists led by ISN faculty announced the detection of Weyl points through a process relying upon a gyroid photonic crystal designed to produce such particles. While the ramifications of the observation of Weyl points are not yet known, they could lead to improved high-power single frequency lasers and optical materials that provide angular selectivity for filtering light regardless of its 3D angle of incidence.

Nano-enabled Incandescent Lighting:
Long considered problematically inefficient, incandescent bulbs nonetheless were the standard for decades. More recently, however, more efficient alternatives such as LEDs and compact fluorescents have replaced incandescent bulbs. Now, a team led by ISN researchers has demonstrated an incandescent bulb that not only improves upon the efficiency of previous incandescents but also fluorescent and LED bulbs.
3D Printed “Tattoo” Made of Living Cells:
A team including ISN-affiliated faculty has devised a new 3D printing technique that uses an ink made of living cells. The tattoo has been designed so that it is responsive to certain chemicals. Future developments could include engineering the “tattoos” to produce medicines, and allowing them to be used in implantable and ingestible devices for the detection of toxins and the administration of medications.

Gaining a Better Understanding of Electron Conductivity in Polymers:
Conjugated polymers have long been considered promising materials for use in a variety of electronics applications, but a lack of fundamental understanding regarding how electrical conduction works in such materials, and an inability to predict their behavior, proved a stumbling-block to researchers. Work by ISN-affiliated MIT faculty and students, in collaboration with scientists at Brookhaven National Laboratory, has provided a new level of understanding of these areas, and could result in both more advanced research and new transparent, flexible, highly conductive polymeric materials.

Transparent Displays Using Nanoparticle Scattering:
With the ubiquity of electronic devices, the need for transparent display technologies will only continue to grow. Currently available transparent displays suffer from issues including limited angles of visibility, low transparency, and high cost. ISN researchers, working with scientists from Harvard University and the US Army Edgewood Chemical/Biological Center, have pioneered a new technology that may alleviate many of these problems by embedding nanoparticles that only scatter light of a particular wavelength in a highly scalable polymer sheet, creating a low cost monochromatic display.
Self-curing Composite Materials:
Composite materials made up of many layers of polymers are used in an array of applications, but a step in their manufacturing - baking them in giant ovens - makes the process far less efficient than it could be. Advances by ISN researchers allow for the heating process to be performed by a film containing carbon nanotubes, and that film can be included in the composite material itself. Not only could this process obviate the need for the industrial oven, it could decrease the energy needed to bake the material, as the heat is sent directly where it is needed.

Angular Selectivity of Light Transmission:
In a breakthrough in the challenge to control the transmission of light through a medium based on the light’s incident angle rather than its frequency or polarization, a team lead by ISN and other MIT researchers working with NSRDEC have theoretically described and experimentally demonstrated a means to enable transparency at a specific angle and reflectivity at all other angles, potentially leading to advances in fields as varied as personal computing, smart optical devices, and astrophysics.

Water-based, Electronic Bandages:
ISN researchers have developed a hydrogel material that could lead to future bandages that can be equipped with electronic devices, including sensors, lights, and drug-delivery tools. For more invasive treatments, these materials could also be implanted inside a patient’s body.
Amplifying Fluorescent Polymers for Ultrasensitive Explosives Detection:
ISN-developed polymers have become the backbone of the FLIR FIDO trace explosives detector, which has been deployed in Iraq and Afghanistan, as well as US airports.

Hollow Fiber for Guiding CO₂ Laser Light Through Air:
Based on ISN-developed hollow cylindrical photonic crystals that can safely guide high-powered laser light through their cores, the OmniGuide high performance CO₂ laser fiber has been used in more than 200,000 procedures at more than 1,000 VA and civilian hospitals, and was supported and funded since its theoretical inception by the US Army.

Efficient Wireless Non-Radiative Power Transfer over Distance:
Providing wireless power over distance at better than 90% efficiency, the WiTricity™ system utilizes magnetic resonance to safely transfer energy. WiTricity™ continues to develop this technology for use with vehicles, medical devices, and Soldier equipment and applications, as well as a host of other purposes.

Nanostructured Photonic Crystal LEDs:
Luminus Devices’ PhlatLight high performance LEDs, reliant upon intrinsic ISN-developed photonic crystals, are currently used in numerous products in general lighting, projection, transportation, entertainment, and other fields.

Thermodynamically Stable Nanocrystalline Alloys:
ISN-developed stable grain boundary-engineered metal alloys from Xtalic can provide dynamically tuned properties – like the strength of steel with the weight of aluminum, or dramatically improved corrosion and wear resistance – for use in a vast array of civilian and military equipment.

Spray Assisted Layer-by-Layer Thin-Film Deposition:
Svaya Nanotechnologies, responsible for the world’s first LbL-functionalized product to market at industrial volume, specialized in a molecular self-assembly process that produces highly uniform films on large-area substrates. Svaya has provided a free LbL coating unit to NSRDEC for laser eye protection material development, and the LbL technology has been acquired by global science giant 3M.

Novel Nanostructured Lipid Shell Constructs for Drug Delivery:
Interblayer-crosslinked multilamellar vesicles (ICMVs) are remarkable drug-delivery particles that help minimize the common problem of medications leaching out into the body before they can reach targeted locations in cells. Used to deliver a malaria vaccine developed with the Walter Reed Army Institute of Research, ICMVs resulted in an immune response that was 10 times that of other delivery methods but required only 1/100th the quantity of vaccine. Further developed by ISN-faculty startup Vedantra, ICMVs are being designed to contain medications for other illnesses.
Quantum Dot LEDs:
Producing narrow-bandwidth red, green, and blue light that generate very pure, saturated images, quantum dot (QD) LEDs by ISN-faculty startup QD Vision are utilized in displays for entertainment and computing purposes by many of the most respected brands in the electronics industry.

Powered Rope Ascension Technology:
Originally developed by a Soldier Design Competition team that subsequently incorporated as Atlas Devices, the Atlas Powered Ascender is a lightweight, battery-powered device that provides as much as 1400 feet of vertical lift up a fixed line and boasts a lifting capacity of as much as 600 lbs. Applications are varied in both the civilian and military communities.

Fracture Dynamics Code:
Enabling large-scale computer simulations of material fracture and structural failure in 3D, ISN-developed discontinuous Galerkin-based ΣMIT (“SUMMIT”) codes from faculty startup ParaSim are used at ARL, PEO-Soldier, NSRDEC, and TARDEC for the analysis of protection systems and injury biomechanics.

Unique Nanoscale Kinematic Alloy Materials:
Based on a bamboo-like oligocrystalline nanostructure, ISN-faculty startup Kinalco’s unique shape memory alloys (SMAs) are made largely from copper, and their ultra-high performance comes at a substantially reduced price when compared to the currently standard NiTi-based SMAs. Kinalco’s SMAs are in development for a number of civilian and military applications, including cabling, device and industrial actuators, orthopedics, electronic connectors, and even clothing.

Defended the ACH before Senate Arms Services Committee Senior Staff:
Cutting-edge biofidelic computational studies of blast impacts on a human head with and without the Advanced Combat Helmet (ACH) categorically refuted earlier National Laboratory studies indicating the potential for increased injury to Soldiers and warfighters wearing the ACH.

Multimaterial Multifunctional Fiber Devices:
ISN-developed optoelectronic fiber devices became a foundational science for Advanced Functional Fabrics of America (AFFOA), the new, multimillion dollar DoD Manufacturing Innovation Institute and member of the Manufacturing USA network previously known as the National Network for Manufacturing Innovation (NNMI). AFFOA seeks to facilitate the transformation of fabrics and textiles into highly enabled, functional devices and platforms.

Direct Transition of ISN Research and Technology to Start-up Companies: 25 startups from ISN 6.1 projects, plus an additional 10 startups from the Soldier Design Competition.
ISN / Lincoln Laboratory Soldier Design Competition

The Soldier Design Competition (SDC) was established in 2003 to engage undergraduate students from the Massachusetts Institute of Technology in the activities of the Institute for Soldier Nanotechnologies, and in 2004 was expanded to include cadets from the United States Military Academy at West Point (USMA).

Drawing on the academic, Army, and industry communities that make up the ISN and, through a strategic partnership that began in 2018, with MIT Lincoln Laboratory, the SDC provides students with hands-on experience in the design and prototyping of technology solutions to real world problems in protection and survivability faced by Soldiers, other warfighters, and first responders.

Teams compete by addressing challenges provided by the Army and Marine Corps’ science and technology, acquisitions, and operations communities. A panel of leaders from the Army, industry, and MIT determines winning prototypes. To date, the SDC has engaged more than 400 MIT students and USMA cadets, who have founded more than a dozen startup companies.

The SDC provides a unique opportunity for students to apply their knowledge and creativity to make a difference for today’s Soldier. Teams develop perspective on how modern technology can help the U.S. military, as well as fire fighters, law enforcement officers, and other emergency response personnel. Army mentors provide SDC team members with advice on the military relevancy and technical viability of proposed technology solutions. Finalists are judged according to the technical design practicality, innovativeness, likely military benefit, and logistical supportability of their prototype technology solutions.

Outreach

Visits

Each year the ISN hosts between 600 and 800 visitors for research briefings and tours of ISN facilities. These visitors hail from a variety of places, including the US Government, US and other military services, industry, and academic institutions across the world. Past visitors have included members of the US Senate and House of Representatives, the Secretary of the US Army, and the Chief of Staff of the US Army.
For more information

If you wish to contact the ISN, please do so by emailing isn@mit.edu.

Institute for Soldier Nanotechnologies
Massachusetts Institute of Technology
77 Massachusetts Avenue, NE47-4F
Cambridge, MA 02139

If you are a media representative looking for additional information about the ISN, or the representative of a company interested in becoming a member of the ISN Industry Consortium, please contact Franklin Hadley, ISN Director of Outreach and Communications, at fhadley@mit.edu.
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The ISN is a part of the Massachusetts Institute of Technology in Cambridge, Massachusetts, and reports directly to the MIT Vice President for Research.