Institute for Soldier Nanotechnologies

Founded in 2002, the Institute for Soldier Nanotechnologies (ISN) is a three-member team designed to leverage the unique capabilities of the US Army, industry, and MIT. The ISN mission is to help the Army dramatically improve the survivability of its soldiers by working at, and extending the frontiers of, nanotechnology through basic research, and then implementing promising outcomes of that research in collaboration with the Army and industry partners. This mission includes not only decreasing the weight that soldiers carry but also improving blast and ballistic protection, creating new methods of detecting and detoxifying chemical and biological threats, and providing physiological monitoring and medical treatment. The ultimate goal is to help the Army create integrated systems of nanotechnologies that combine high-tech protection and survivability features with low weight, increased comfort, improved performance, and better compatibility with the end user.

Army funding for ISN basic research is approximately $135 million over 15 years, dispensed through renewable five-year contracts administered by the US Army Research Office. There is also substantial co-investment by industry partners and MIT. Following a series of reviews by the Army, ISN was approved for the renewal of its five-year contract in 2012. The contract for ISN-3 was signed on December 27, 2012.

Approximately 30 faculty members from a dozen MIT academic departments, as well as more than 100 graduate students and postdoctoral associates, participate in ISN research. ISN research appears in more than 125 refereed publications annually and in distinguished scientific journals, including *Science*, *Advanced Materials*, *Nature*, *Physical Review Letters*, and the *Proceedings of the National Academy of Sciences*. More than 350 people have visited ISN over the past year for briefings on research endeavors and tours of ISN facilities. On January 14, 2015, ISN was privileged to host Lieutenant General Michael Williamson, the principal military deputy to Assistant Secretary of the Army for Acquisition, Logistics and Technology Heidi Shyu. On September 19, 2014, ISN was honored to host Ms. Shyu herself.

Research

ISN's signature interdisciplinary research agenda evolved over the course of its first 10 years into a focused program reflecting the areas where ISN and the Army see the potential for especially strong soldier impacts emerging. For ISN-3, this structure has been further updated and redefined to align with, and respond more efficiently to, guidance from the Army. Team-based innovation is a hallmark of ISN's intellectual course, with new ideas and collaborations emerging frequently. The ISN research portfolio is currently divided into five strategic research areas (SRAs) that are, in turn, further divided into themes and then specific projects.

Strategic Research Area 1: Lightweight, Multifunctional, Nanostructured Materials and Hybrid Assemblies

Strategic Research Area 1 (SRA1) emphasizes the creation of nanoscale and nanostructured building blocks to provide diverse protective capabilities such as sensing, communications, night vision, electronic devices, and visibility management. Examples of these building blocks are nanocrystals (quantum dots), novel carbon forms (graphenes, carbon nanotubes), optoelectronic fibers, coatings, interfaces, and hybrid nanostructures.

- Theme 1.1: Quantum Dots for Wide-Bandwidth Imaging and Communications
    - Project 1.1.1: Hybrid Quantum Dot-Based Imagers and Emitters with Broadly Tunable Spectral Characteristics
- Theme 1.2: Nanoscale Carbon Forms for Situational Awareness
    - Project 1.2.1: Graphene Devices for Next-Generation Night Vision Systems
- Theme 1.3: High-Functionality Nanostructured Surface Capabilities
    - Project 1.3.3: Enabling Architectures and Technologies for Next-Generation Fiber Devices
- Theme 1.4: Environmental Obfuscation and Extended Reach Situational Awareness
    - Project 1.4.1: Tailored Nanoparticles for Obscurant Applications

Strategic Research Area 2: Soldier Medicine—Prevention, Diagnostics, and Far-Forward Care

Strategic Research Area 2 (SRA2) focuses on medical diagnostics and treatment for soldiers with particular emphasis on enabling far-forward and remote area care. Far-forward and remote area care include immediate as well as longer-term treatment of battlefield injuries through improved drug preservation and delivery, treatment of hemorrhagic shock, wound healing, and neuromedicine.

- Theme 2.1: Disease Prevention: Nanoengineered Drug Delivery and On-Demand Protection
    - Project 2.1.1: Nanotechnology for Stimulating, Sampling, and Monitoring Immunity
- Theme 2.2: Drug Preservation, Dose Preformulation, and Far-Forward Administration
    - Project 2.2.1: Rapid Reconstitution Packages of Lyophilized Medicines
- Theme 2.3: Materials and Devices for Emergency and Long-Term Treatment of Battlefield Injuries
    - Project 2.3.1: Nanostructured Biomaterials for Treatment of Hemorrhagic Shock
    - Project 2.3.2: Multicomponent Nanolayer Assemblies for Soldier Wound Healing
    - Project 2.3.3: Delivery of Brain Lipid Nanoparticles Using Microtech Devices for Treatment of Traumatic Brain Injury

- Project 2.3.4: Complementary Wound-Healing Strategies Enabled by Synthetic Biology and Nanotechnology

Strategic Research Area 3: Multiple Blast and Ballistic Threats—Materials Damage, Human Injury Mechanisms, and Lightweight Protective Systems

The aim of Strategic Research Area 3 (SRA3) is to develop new, lighter-weight protective materials systems for improved protection from blast, ballistic, and blunt trauma, as well as to obtain increased understanding of materials failure and human injury caused by blast and other forms of mechanical energy. This understanding is used to guide the design and formulation of novel protective materials with potential applications for the dismounted and the mounted soldier.

- Theme 3.2: Metallic Alloys, Fibers and Fabrics for Protection and High-Capacity Mechanical Energy Damping
  - Project 3.2.1: Layered/Graded Nanocrystalline and Superelastic-Fiber Alloys for Lightweight Protection
- Theme 3.3: Blast-Induced Injury: Physical Mechanisms, Biological Responses, and Physiological Outcomes
  - Project 3.3.1: Blast-Induced TBI—Connections Among the Physical, Biological, and Behavioral Dimensions
  - Project 3.3.2: Electromechanical Interactions in Blast-Induced Traumatic Brain Injury
  - Project 3.3.3: Molecular to Macroscale Exploration of Fundamental Properties of Gels
- Theme 3.4: Multiscale Modeling, Simulation, and Measurements of Blast and Ballistic Damage to Protective Materials and Systems
  - Project 3.4.1: Advanced Computational Tools for Multiscale Modeling and Simulation of Multithreat Protective Systems
- Theme 3.5: Advanced Concepts for Lightweight, Flexible Protective Materials
  - Project 3.5.2: Design and Synthesis of Carbon-based Chainmaille Structures for Flexible, Ultra-lightweight Protection

Strategic Research Area 4: Hazardous Substances Sensing, Recognition, and Protection

Strategic Research Area 4 (SRA4) focuses on exploring and enabling new mechanisms for the high-sensitivity detection of molecularly complicated hazardous substances, such as chemical and biological agents, food-born pathogens, and explosives, as well as individual toxicants in complex organic mixtures, and on methods to detect human exposure to toxins and to protect humans from hazardous biological substances such as viruses and bacteria.

- Theme 4.1: Sensing of Toxic Substances, Exposure Biomarkers, and Explosives Using Integrated Nanostructured Platforms
    - Project 4.1.2: Resistivity-Based Microfluidic Biosensing
    - Project 4.1.4: Molecular Recognition Using Carbon Nanotube Adsorbed Polymer and Bio-Polymer Phases: Synthetic Nanotube Templated Antibodies
- Theme 4.2: Quantum Dots for Chemical and Biological Sensing
    - Project 4.2.1: Chemical-Biological Analyte Sensing with Hybrid Quantum Dot Constructs

Strategic Research Area 5: Nanosystems Integration for Protected Communications, Diagnostic Sensing, and Operational Flexibility in Complex Environments

The goal of Strategic Research Area 5 (SRA5) is the integration of nanoscale and nano-enabled materials and devices into systems that provide soldiers with enhanced flexibility to operate in complex environments (e.g., through capabilities to sense toxic chemicals, pressure, and temperature, shield electronics from electromagnetic interference, detect sound and other mechanical vibrations) and allow groups of soldiers to communicate free of enemy eavesdropping.

- Theme 5.1: Optoelectronic Fiber Platforms with Real-time Modulation Capabilities
    - Project 5.1.1: Ferroelectric Acoustic Fibers
- Theme 5.2: Multicapability Systems for Communications, Sensing, and Signal Processing
    - Project 5.2.1: Multifunctional Integrated Fabrics
    - Project 5.2.2: Enabling Novel Lightwave Phenomena
    - Project 5.2.3: Spatial Awareness Around Corners
- Theme 5.3: Lightweight Power and Energy for Enhanced Uniform Functionality and Protection
    - Project 5.3.1: Novel Thermal Radiation Management Using Advanced Photonic Crystals

Transitioning

ISN places a strong emphasis on basic research. However, the transitioning of promising outcomes of that research is also a crucial component of ISN's mission. To this end, ISN works with the Army, industry partners, startups and other companies, and with the MIT Technology Licensing Office to help ensure that promising ISN innovations leave the laboratory and reach the hands of soldiers and first responders as rapidly and efficiently as possible. ISN is pleased to have an Army technology transfer officer on its full-time headquarters team. It is the technology transfer officer's charge to help maximize the effectiveness and efficiency with which ISN technologies progress from the laboratory bench to more advanced stages of development.

A Small Sampling of ISN Research Accomplishments

Angular Selectivity of Light Transmission

In a breakthrough in controlling the transmission of light through of the light's incident angle rather than its frequency (Figure 1), ISN and MIT researchers, in collaboration with scientists at China's Zheijang University, 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 and astrophysics. Further details of this work have been published in a scholarly article in the journal Science.

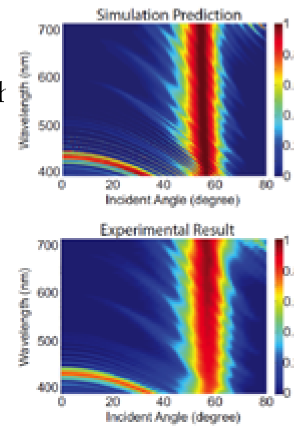

Figure 1. The strong correlation between predicted behavior and experi-mental results in the angular selectivity of light transmission

Transparent Displays Using Nanoparticle Scattering

Figure 2. A non-optimized prototype of the transparent display, showing a projected MIT logo in front of three MIT mugs to illustrate the system's transparency.

Given the ubiquity of electronic devices, the need for transparent display technologies will only continue to grow. Currently available transparent displays suffer from a number of problems, including limited angles of visibility, low transparency, and high cost. ISN researchers, working in conjunction with scientists from Harvard University and the US Army Edgewood Chemical/Biological Center, have pioneered a new technology that has the potential to alleviate many of these problems (Figure 2). The new approach embeds nanoparticles that scatter only light of a particular wavelength in a highly scalable polymer sheet, creating a low-cost monochromatic display. Further details of this work have been published in a scholarly article in the journal Nature Communications.

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 member Moungi Bawendi, working with former postdoctoral associate Jie Bao (now a professor at Tsinghua University in Beijing, China), has devised a possible solution to these challenges. By using a planar array of quantum dots, Professor Bawendi's device obviates the need for complex optics and multiple filters, allowing different spectra to be distinguished using a single filter and a single detector. Further details of this work have been published in a scholarly article in the journal Nature.

The Experimental Observation of Weyl Points

Despite their theoretical prediction by the German physicist and mathematician Hermann Weyl in 1929, building on earlier work by the English physicist Paul Dirac, "Weyl points," as they came to be known—massless subatomic particles—escaped experimental observation for 86 years. In early 2015, an international team of scientists led by Professor Marin Soljačić and ISN Director Professor John Joannopoulos announced the detection of Weyl points through a process relying upon a gyroid photonic crystal that was precisely designed to produce such particles (Figure 3). Although the full ramifications of this observation are not yet known, Weyl points could lead to improved high-power single-frequency lasers as well as optical materials that provide angular selectivity for filtering light regardless of its three-dimensional angle of incidence. Further details of this work have been published in a scholarly article in the journal Science.

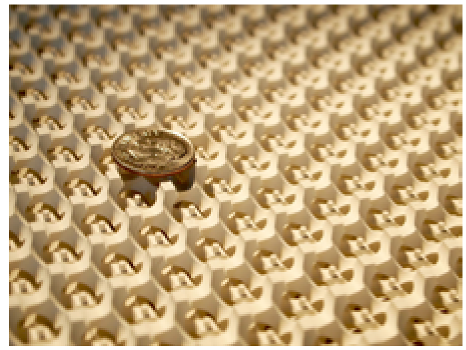

Figure 3. A novel photonic crystal design, shown above with a dime for scale, was critical to the manifestation of Weyl points

Historically Black Colleges and Universities and Minority Institutions Program

In 2007, with Professor Paula Hammond as program director, ISN began a program to engage faculty and students from historically black colleges and universities and minority institutions (HBCU-MIs) in research in support of the ISN mission. This program funds peer-reviewed basic research projects at HBCU-MIs and facilitates collaborations between HBCU-MI and ISN scientists. Also, visiting faculty and students from HBCU-MIs can use ISN research facilities. Currently, ISN funds two faculty-led projects through its HBCU-MI program; one is at the City College of New York, the other at Howard University.

Army Collaboration

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 (the technological maturation and scale-up of the outcomes of ISN basic research). ISN has collaborated with many Army science and technology laboratories and centers, including:

- Armament Research, Development, and Engineering Center at Picatinny Arsenal

- Army Research Laboratory (including the Army Research Office, Computational and Information Sciences Directorate, Human Research and Engineering Directorate, Sensors and Electron Devices Directorate, and Weapons and Materials Research Directorate)
- Aviation and Missile Research, Development, and Engineering Center
- Communications-Electronics Research, Development, and Engineering Center
- Defense and Veterans Brain Injury Center
- Edgewood Chemical/Biological Center
- Madigan Army Medical Center
- Natick Soldier Research, Development, and Engineering Center
- Program Executive Office—Soldier
- Tank Automotive Research, Development, and Engineering Center
- US Army Corps of Engineers
- US Army Research Institute of Environmental Medicine
- Walter Reed Army Institute of Research

Other Department of Defense and Government Collaboration

Although ISN's first customer remains the soldier, many research projects have broad appeal not only to the US Department of Defense but also to other government agencies. Collaborations and interactions have occurred with a number of the Army's sister services and other US government entities, such as:

- Camp Roberts
- Deployed Warfighter Protection Program
- Naval Postgraduate School
- Naval Sea Systems Command
- US Air Force Medical Service
- US Air Force Special Operations Command
- US Department of Agriculture
- US Food and Drug Administration
- US Special Operations Command
- Walter Reed National Military Medical Center

Industrial Collaboration

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 quantities needed by various end users. ISN industry partners include:

- Center for Integration of Medicine and Innovative Technology (CIMIT)
- FLIR Systems
- JEOL USA
- Lockheed Martin
- Nano-C
- Raytheon
- Total American Services
- Triton Systems
- VF Corporation
- Xtalic

Outreach Activities

Soldier Design Competition

The ISN Soldier Design Competition (SDC) was established in 2003 to engage MIT undergraduates in the activities of ISN. In 2004, the competition was expanded to include cadets from the United States Military Academy at West Point (USMA) (Figure 4). The SDC provides a unique opportunity for students to apply their knowledge and creativity while gaining hands-on experience in the design and prototyping of technology solutions to problems faced by today's soldiers and first responders. Teams compete for prize money donated by industry companies that have included Boeing, General Dynamics, L-3 Communications, Lockheed Martin, QinetiQ North America, Raytheon, and W.L. Gore and Associates. Each year, a panel of leaders from the Army, industry, and MIT determines the winning prototypes.

Figure 4. The logo from SDC 12, combining the colors and fonts of the ISN logo with the shield shape of the USMA logo.

Teams address challenges supplied by the Army and Marine Corps' Science and Technology, Acquisition, and Operations Communities. SDC participants meet active-duty soldiers and Marines, and develop perspective on how modern technology can help the US military as well as firefighters, 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 prototypes. Competitors are encouraged to further develop and commercialize their inventions.

The winning team at SDC12 was a group of USMA students who developed a device that minimizes the visible flash and audible report of the Army's standard M249 light machine gun. The Silent Knight team took home the first place Lockheed Martin Prize/Raytheon Prize of $7,000.00 for their work. Another USMA team took second place, and the $5,000.00 Lockheed Martin/Raytheon Prize, for devising a lightweight building material that incorporates a phase change substance to regulate the temperature inside the resulting structure.

ANTS Presentations

The ISN Army Nanotechnology Seminar (ANTS) series is designed to foster the exchange of information related to research on soldier protection, equipment, health, and other needs. These seminars, held during the fall and spring semesters, also offer ISN researchers, graduate students, and postdoctoral associates the opportunity to learn more about research that is under way at Army labs and other facilities. To help ISN's colleagues at other locations participate, ANTS are webcast using collaboration software that facilitates real-time interaction. Remote participants can watch and listen to presentations, and are able to engage in question-and-answer sessions

Figure 5. ISN ANTS Presentations are a key means of sharing information between MIT scientists, industry partners, and Army researchers.

ISN Website and Partner Portal

ISN had long maintained a standalone Industry Collaboration Portal, independent of the main ISN website, as a focus of information with its industry partners (Figure 6). In early 2014, a completely redesigned ISN website was activated that includes an enhanced Partner Portal, with protected access provided not only to ISN partner companies but also to key Army personnel. The integrated Partner Portal effectively expands the Industry Collaboration Portal, improving the amount of information available, the site's ease of use, and the communities served.

Figure 6. The ISN website contains a password-protected portal for sharing important information with ISN constituents.

Contributions to the MIT Community

ISN maintains more than 40,000 square feet of space in a dedicated facility located in Cambridge's Technology Square (Figure 7). More than 450 registered users from across MIT have access to ISN facilities that include wet and dry laboratories, computer clusters, and mechanical testing and other research instrumentation, including equipment for low- and high-rate mechanical characterization of the dynamic response of materials, electron microscopy, and femtosecond laser spectroscopy.

Figure 7. ISN headquarters and labs occupy the fourth and fifth floors of 500 Technology Square (NE47) in Cambridge, MA.

In addition, since the start of the second ISN contract in August 2007, ISN has provided more than $6.9 million in seed and augmentation funding for MIT research projects, supporting research in a variety of different academic departments and research centers.

Future Plans

The ISN mission remains extremely relevant to the needs of the soldier and the nation. In the short term, ISN looks forward to revising its research portfolio to be even more responsive to the Army's needs and to further align itself with the Army's research and technology roadmap. Over the coming years, ISN will seek to build and further strengthen partnerships with the Army, other US military services, and industry while refocusing and streamlining the ISN portfolio of basic research projects in response to new opportunities and evolving customer needs. Working as an Army–industry–university team, ISN will continue to perform basic research and transitioning to improve soldiers' protection and survival.

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