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 dramatically improve the survivability of the soldier by working at and extending the frontiers of nanotechnology through basic research and transitioning promising outcomes of that research in collaboration with our 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 far-forward medical treatment. The ultimate goal is to help the Army create an integrated system of nanotechnologies that combines high-tech protection and survivability capabilities with low weight and increased comfort.

Army funding for ISN basic research is approximately $150 million over 15 years, dispensed through renewable five-year contracts administered by the US Army Research Office (ARO). 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.

Each year more than 50 faculty members from 14 MIT departments, labs, and centers, as well as approximately 75 graduate students and 50 postdoctoral associates, participate in ISN research, producing more than 150 refereed publications in journals such as *Nature*, *Physical Review Letters*, *Advanced Materials*, and the *Proceedings of the National Academy of Sciences*. Additionally, approximately 500 people have visited ISN over the past year for briefings on research endeavors and tours of ISN facilities. On April 2, 2013, ISN was privileged to host assistant secretary of defense Sharon E. Burke at the request of professor Ernest Moniz, then a nominee for Secretary of Energy.

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 emerging for especially strong soldier impacts. This structure remains substantially intact for the ISN-3, though specific areas have been repositioned and redefined to better align with and more efficiently respond to Army needs. Team-based innovations are a hallmark of ISN's intellectual course, with new ideas and collaborations emerging frequently. Areas of research interest are 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

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 and carbon nanotubes), optoelectronic fibers, coatings, interfaces, and hybrid nanostructures.

- Theme 1.1 - Quantum Dots for Wide-Bandwidth Imaging and Communications
- Theme 1.2 - Nanoscale Carbon Forms for Situational Awareness
- Theme 1.3 - High-Functionality Nanostructured Surface Capabilities
- Theme 1.4 - Environmental Obfuscation and Extended-Reach Situational Awareness

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

SRA2 focuses on medical diagnostics and treatment for the soldier with particular emphasis on enabling far-forward and remote area care including immediate as well as longer-term treatment of battlefield injuries, e.g., through drug preservation and delivery, treatment of hemorrhagic shock, wound healing, and neuromedicine.

- Theme 2.1 - Disease Prevention: Nano-engineered Drug Delivery and On-Demand Protection
- Theme 2.2 - Drug Preservation, Dose Pre-formulation, and Far-Forward Administration
- Theme 2.3 - Materials and Devices for Emergency and Long-Term Treatment of Battlefield Injuries

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

The aim of 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 due to blast and other forms of mechanical energy. This understanding is, in turn, used to guide the design and formulation of novel protective materials with potential applications for the dismounted and the mounted soldier.

- Theme 3.1 - Nano-engineered Composites and Fibers for Ballistic, Blast, and Blunt Trauma Protection
- Theme 3.2 - Metallic Alloys, Fibers, and Fabrics for Protection and High-Capacity Mechanical Energy Damping
- Theme 3.3 - Blast-Induced Injury: Physical Mechanisms, Biological Responses, and Physiological Outcomes

- Theme 3.4 - Multi-scale Modeling, Simulation, and Measurements of Blast and Ballistic Damage to Protective Materials and Systems
- Theme 3.5 - Advanced Concepts for Lightweight, Flexible, Protective Materials

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

SRA4 focuses on exploring and enabling new mechanisms for the high-sensitivity detection of molecularly complicated hazardous substances, e.g., chemical/biological agents, food-born pathogens, and explosives, as well as individual toxicants in complex organic mixtures. This strategic research area also focuses 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 Nano-structured Platforms
- Theme 4.2 – Quantum Dots for Chemical/Biological Sensing

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

The goal of SRA5 is the integration of nanoscale and nano-enabled materials and devices into systems that provide the soldier with enhanced flexibility to operate in complex environments (e.g., through capabilities to sense toxic chemicals, pressure, and temperature; shield electronics from electromagnetic interference; and 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
- Theme 5.2 - Multi-capability Systems for Communications, Sensing, and Signal Processing
- Theme 5.3 - Lightweight Power and Energy for Enhanced Uniform Functionality and Protection

Transitioning

ISN places a strong emphasis on basic research. However, the transitioning of promising outcomes of that research is also a crucial component of our mission. ISN works closely with the Army, industry partners, startups, and other companies to help assure that promising ISN innovations leave the lab and make it into the hands of soldiers and first responders as rapidly and efficiently as possible.

A Small Sampling of ISN Research Accomplishments and Transitions

Optoelectronic Fibers

Unlike traditional approaches for making "smart" fabrics, which center on attaching devices to conventional woven materials, this ISN research focuses on the development of unique fibers that are themselves optoelectronic devices. Already fibers have been produced that detect light, heat, and sound. Future applications could include combat identification, infrared communications, sniper detection, medical imaging, and blast and blunt impact monitoring. Previously a hollow fiber that internally guides CO_2 laser light with essentially no attenuation was transitioned to the startup company OmniGuide, and is being used in approximately 600 civilian and Veterans Administration hospitals across the US to perform more than 1,000 endoscopic surgeries every month.

Detection of Hazardous Substances

ISN faculty and researchers have pioneered the development of a novel class of molecular chromophore systems called amplifying fluorescent polymers (AFPs). These AFPs, long molecules that glow under certain conditions, enable the ultra-high-sensitivity detection of explosives and other hazardous materials. In partnership with FLIR Systems and (previously) ICx Technologies and ICx Nomadics, devices incorporating AFPs have been developed and fielded in Iraq and Afghanistan. A variation on this technology has been transitioned to the Transportation Security Administration for the detection of liquid explosives at airports.

Blast and Ballistic Protection

By capitalizing on unique deformation mechanisms that exist at nanoscale dimensions, ISN is developing materials with increased strength and energy-dissipation characteristics. One example is the fabrication of nanoparticle metal alloys that combine the high strength of steel with the low weight and high ductility of aluminum. These alloys have been transitioned to the Army Research Laboratory, Picatinny Arsenal, and the MIT startup Xtalic for scale-up, testing, and further development.

While the development of advanced protective materials is a vital component of ISN research, it is also necessary to understand how materials fail, how to improve materials to make them stronger and lighter, and what happens behind armor that is exposed to a strong mechanical force. ISN is investigating all of these questions through the development of high-fidelity predictive mathematical modeling and simulation tools. A key example is an ISN collaboration with the Army to construct an extremely realistic human head and helmet model in order to explore the effect of blast wave impacts (e.g., from improvised explosive device explosions) on the soldier.

Health Monitoring, Protection, and Treatment

Nanostructured materials hold extraordinary potential for improved medical care. In a joint ISN-Army malaria vaccine study using a murine model, a newly developed ISN nanoparticle, called an interbilayer-crosslinked multilamellar vesicle provided a tenfold increase in immune response with 100 times less vaccine. Moreover, the immune response remained essentially unchanged for more than five months.

Additionally, rapid reconstitution packages of lyophilized drugs have been developed to greatly simplify logistics, dramatically prolong drug shelf life, and increase ease of administration in the field.

Wireless Power

Although the feat was long thought impossible, ISN faculty and researchers were able to transmit electric power wirelessly and non-radiatively over a distance of two meters using two strongly coupled magnetic resonators. Startup company WiTricity is developing this technology. Moreover, Army scientists at the Natick Soldier Research, Development, and Engineering Center (NSRDEC) are investigating applications to power helmet-mounted devices without connecting wires, while the Army's Rapid Equipping Force, in collaboration with ISN partner QinetiQ North America, is researching the remote charging of robots. Recent WiTricity advances that enable the transfer of 3.3kW over a distance of one-half meter at over 90 percent efficiency have opened the possibility of the cordless charging of electric vehicles.

Gentle Chemical Vapor Deposition

Chemical vapor deposition (CVD) is a widely used industrial means of coating surfaces. However, the harshness of the process has dramatically limited the types of materials used as the substrate and the depositant. Gentle CVD, pioneered by the ISN faculty, enables the deposition of thin (nm to μm) conformal coatings of heat- and chemically sensitive polymers on diverse substrates. Startup company GVD is transitioning various types of gentle CVD for a range of applications, including water repellency and other forms of surface protection. ISN partner Raytheon, in collaboration with NSRDEC, is exploring the use of gentle CVD to reduce the weight of shielding on electrical cables. NSRDEC has also used gentle CVD to dramatically improve the performance of sensors for the detection of food-borne pathogens.

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 utilize ISN research facilities.

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 (i.e., technological maturation and scale-up of the outcomes of ISN basic research). ISN maintains substantial interactions with many Army science and technology laboratories and centers, including:

- Army Research Laboratory
- Aviation and Missile Research, Development, and Engineering Center
- Communications-Electronics Research, Development, and Engineering Center
- Edgewood Chemical/Biological Center
- Madigan Army Medical Center
- Natick Soldier Research, Development, and Engineering Center
- Picatinny Armament Research, Development, and Engineering Center
- 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

While ISN's first customer remains the Army, ISN also has had substantial interactions and collaborations 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
- 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 was proud to welcome 3M as a new industrial partner this past year. Current membership of the ISN Industry Consortium includes:

- 3M
- Center for Integration of Medicine and Innovative Technology
- FLIR Systems
- JEOL USA
- Nano-C
- Nike
- Northrop Grumman
- QD Vision
- QinetiQ North America
- 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, SDC expanded to include cadets from the United States Military Academy at West Point (USMA). 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 soldier and first responder. 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 winning prototypes.

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. Competitors also own intellectual property from their ideas and are encouraged to further develop and commercialize their inventions.

The winner of SDC10 was a team of USMA cadets that developed an environmentally friendly disinfectant that would not only clean pathogens and other contaminants, but also deter crickets, stinkbugs, and a variety of other pests that a soldier might encounter in the field. The top MIT team designed a lightweight, helmet-mounted airbag system to help protect against head and neck injuries and prevent damage from flame and debris.

Army Nanotechnology Seminar Presentations

The ISN Army Nanotechnology Seminar (ANTS) series fosters the exchange of information related to research on soldier protection, equipment, health, and other needs. These monthly seminars also offer ISN researchers, graduate students, and postdoctoral associates the opportunity to learn more about research under way at Army labs and other facilities.

To help our colleagues at other locations participate, seminars are webcast using collaboration software that facilitates real-time interaction. Remote participants can watch and listen to presentations, and engage in questions and answers.

Highlights of the 2012–2013 ANTS season included a talk by Army Research Laboratory Fellow Jan Andzelm on the multiscale modeling of polymers, a presentation by ISN principal research scientist Ivan Celanovic on high-temperature nanophotonics-enabled solid-state energy conversion, and a special seminar on nanocrystalline-diamond thin films by Materials Research Society president and University of Texas at Dallas professor Orlando Auciello.

Summer Internships

In 2008, working with Army colleagues at the Army Labs Summer Internships, ISN began a summer internship program to provide MIT students with opportunities to perform research at Army laboratories under the guidance of Army scientists. Marlisha McDaniels of the ISN Headquarters team is the program coordinator.

MIT students gain an introduction to cutting-edge Department of Defense (DOD) research at world-class Army laboratory facilities while forging professional relationships and discovering potential new career opportunities within the DOD science and technology community. ISN and the Army co-invest to cover student salaries and living expenses.

In the summer of 2013, four MIT freshmen and sophomores participated in the ISN-Army Labs Summer Internship Program, and worked at Army facilities in Aberdeen, MD, and Concord, MA.

ISN also participates in the West Point Advanced Individual Academic Development program. Each summer, ISN welcomes cadets from the USMA Department of Systems Engineering, who engage in short-term research projects. In the summer of 2013, two USMA cadets participated in the program at ISN.

Industry Collaboration Portal

Over the past year, ISN has developed, implemented, and continually improved upon an Industry Collaboration Portal, a password-protected information-sharing wiki site designed to help better inform ISN constituents of new and emerging research, recent and upcoming visitors, and important events. The ISN wiki is updated on a monthly basis. Plans for the coming months include the incorporation of the industry collaboration portal into a completely redesigned ISN website, offering our partners more convenient access to pertinent information.

Contributions to the MIT Community

ISN maintains over 40,000 square feet of space in a dedicated facility located in Cambridge's Technology Square. More than 450 registered users from across MIT have access to ISN facilities that include wet and dry labs, 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.

Additionally, since 2006 ISN has provided more than $4 million in seed and augmentation funding for MIT research projects.

Future Plans

The ISN mission remains extremely relevant to the needs of the soldier and the nation. During the next five years, ISN plans to further strengthen its partnership with the Army and industry and to enrich its portfolio of basic research by involving a number of new faculty members. Working as an Army-industry-university team, ISN will continue to perform basic research and transitioning to improve soldier protection and survivability.

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