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 fundamental research and transitioning with 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 automated medical intervention. The ultimate goal is to help the Army create a 21st-century battlesuit that combines high-technology protection and survivability capabilities with low weight and increased comfort.

Army funding for ISN basic research is approximately $100 over 10 years and is dispensed through renewable five-year contracts administered by the U.S. Army Research Office. There is also substantial coinvestment by industry partners and MIT. ISN is currently being reviewed by the Army for a new five-year contract, which would begin August 1, 2012.

Each year approximately 50 faculty members from 12 MIT academic departments, 75 graduate students, and 45 postdoctoral associates participate in ISN research, producing more than 200 refereed publications in journals such as *Nature*, *Nature Materials*, *Nature Nanotechnology*, *Advanced Materials*, and *Proceedings of the National Academy of Sciences*. Additionally, typically 500–700 people visit ISN annually for briefings on research endeavors and tours of ISN facilities.

In September 2010, the ISN director and associate director were invited to meet with senior staffers at the U.S. Senate Armed Services Committee to provide them with key information relevant to soldier protection under blast events.

In February 2011, ISN was privileged to host U.S. Senator Scott Brown (R-MA), who was joined by president Susan Hockfield and Raymond Stata ’57, SM ’58, cofounder and chairman of Analog Devices, Inc., in remarks in support of legislation cosponsored by Senator Brown and Senator Amy Klobuchar (D-MN) to facilitate industry funding of university research.

Research

ISN’s signature interdisciplinary research agenda evolved over the course of its first five years into a more focused program, reflecting those areas where ISN leadership and the Army see the potential for especially strong soldier impacts to emerge. The renewed contract, enacted in 2007, supports a substantially streamlined research structure. Still, team-based innovation continues to be a hallmark of ISN’s intellectual course, as new ideas and collaborations emerge. 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 Fibers and Materials

ISN's exploration into the development of multifunctional fibers and constructs takes many forms, and is concerned with research to impart diverse, nano-enabled functionalities to materials that can serve as building blocks for clothing and other gear to provide soldier protection and survivability. Of particular interest are nanoscale coatings, core-shell and rod-rod nanostructures, carbon nanotubes, fibers, fabrics, and layered and membrane structures. In SRA-1, there are seven projects across five themes:

- Theme 1.1: Surface Active Multifunctional Fibers
- Theme 1.2: Smart Quantum Dots: Microfluidic Fabrication, Detection, and Sensing
- Theme 1.3: Imaging, Sensing, and Other Applications with Carbon-nanotube Devices
- Theme 1.4: Multimaterial Multifunctional Fibers
- Theme 1.5: Functional and Responsive Elastomers

A portion of the research in SRA-1 results from a fundamental fiber technology unique to ISN. Professor Yoel Fink has pioneered the field of optoelectronic fiber devices. Beginning with a macroscale preform, a thermal drawing process can create kilometers of fiber that contains down its length the materials of modern electronic devices. By manipulating the materials and architectures within the fiber, Professor Fink has achieved a myriad of different devices, from a laser waveguide commercialized for surgical applications to a fiber diode, as detailed in the *MIT News* article "Spinning New Materials in a Thread" (May 19, 2011).

Strategic Research Area 2: Battlesuit Medicine

SRA-2 is concerned with research that can lead to improved medical and combat casualty care for the soldier. Of particular interest are nano-enabled materials and devices applicable to far-forward medical treatment. In the nearer term, these would find application in field hospitals and via battlefield medics. In the longer term, monitoring, diagnostic, and treatment technologies derived from the basic research of SRA-2 would be incorporated in the multicapability battlesuit. Ultimately, qualified medical personnel and soldiers in the field could activate these technologies. Autonomous activation would also be possible, with appropriate safeguards including soldier and medic override capabilities. Examples of SRA-2 research include polymer actuators for imparting rigidity-on-demand (e.g., for splinting wounds or preventing adverse movements after head or neck injury), materials and devices to enable controlled release of medications, methods for accelerated diagnostics of adverse medical conditions, and a microelectromechanical systems–based device to prevent hemorrhagic shock. In SRA-2, there are a total of six projects across three themes:

- Theme 2.1: Nanostructured Actuators: First Principles Prediction to Fabrication
- Theme 2.2: Nanostructured Films and Functional Surfaces for Battlefield Medicine
- Theme 2.3: Noninvasive Medical Monitoring and Drug Delivery

SRA-2 continues to be a strong source of cutting-edge medical science. One prime example of this production is a paper by professor Angela Belcher, published in *Nature Nanotechnology* (April 24, 2011), detailing the real-time examination of living cells with high-speed atomic force microscopy. Professor Belcher and her team have used this technology for the imaging of an antimicrobial peptide acting on E. coli cells, resulting in data indicating that the killing process has two phases: an incubation phase that takes minutes or seconds to complete, and a rapid execution phase.

Strategic Research Area 3: Blast and Ballistic Protection

SRA-3 concentrates its research on blast and ballistic protection. Recognizing the importance of blast-related soldier injuries in current operations, ISN has increased its efforts in blast protection. This complements and enriches its ballistic protection research. In particular, SRA-3 directs considerable assets toward understanding blast interactions with materials including human (brain) tissue as well as various anthropogenic energy-absorbing materials, including microframe structures that contain nanotrusses. In SRA-3, there are a total of nine projects allocated among three themes:

- Theme 3.1: Lightweight Nano-architectures for Ultra-strong and Energy-absorbing Materials
- Theme 3.2: Materials and Structures for Blast Protection and Injury Mitigation
- Theme 3.3: Lightweight Nanocrystalline Alloy Fibers for Impact and Blast Protection

Over the past year, notable progress in SRA-3 has occurred in the modeling of biological structures and materials. Professor Raul Radovitzky published an article in *Proceedings of the National Academy of Sciences* (November 30, 2010), in which he demonstrated that while the Army's current advanced combat helmet did not substantially mitigate the transmission of blast waves through a soldier's brain, it also did not increase the pressure of the blast wave, as had previously been asserted by other research. In order to better understand the propagation of blast waves through a soldier's brain, and the effects of those blast waves as one possible cause of traumatic brain injury, Professor Radovitzky and colleagues developed the most accurate known models of the human head and, to maximize their benefit to the soldier, made those models available to the scientific and medical communities.

Strategic Research Area 4: Chemical/Biological Detection and Protection

SRA-4 is concerned with research to provide new scientific and engineering understanding to enable the detection of hazardous substances in the environment, as well as a means to protect the soldier from those substances. The research will provide foundational information for transitioning of promising outcomes by the Army and industry partners. One activity focuses on different means to obtain nanoscale polymeric coatings that provide specific protective functionalities. Another thrust concentrates on different approaches to the sensing and characterization of various materials, including toxic substances. A third activity seeks to develop the understanding needed to manufacture multilayered 3D nanostructures from foldable 2D nanopatterned surfaces. Potential applications include the ability to scaffold and integrate multiple threat detection capabilities in lightweight and low-energy consumption platforms. In SRA-4, there are a total of five projects across three themes:

- Theme 4.1: Functional, Switchable, and Microbicidal Nanocoatings
- Theme 4.2: Ultrasensitive Nanoengineered Chemical Detectors
- Theme 4.3: Nanostructured Origami

The past year has seen substantial advances in the research under SRA-4, as demonstrated by the *MIT News* article "Finding a Needle in a Haystack" (May 9, 2011), which detailed work by the research group of professor Michael Strano. Professor Strano has developed carbon nanotube-based sensing technology capable of detecting hazardous materials at the single-molecule level. A paper on this research was published in *Proceedings of the National Academy of Sciences* (May 24, 2011).

Strategic Research Area 5: Nanosystems Integration

Systems of components that contain nanoscale materials and devices can enable powerful protection and survivability capabilities for the soldier. SRA-5 is concerned with research to create or exploit such nanoscale materials and devices and to understand their behavior within capability-enabling systems. Work in SRA-5 includes nanoelectronic devices, unique ISN metal-insulator-semiconductor fibers, fabric-enabled communications, and nanostructured materials for observable optical nonlinear responses at very low power levels. The research in SRA-5 is divided among five projects housed in four themes:

- Theme 5.1: Nanoelectronics
- Theme 5.2: Integrated Fiber and Fabric Systems
- Theme 5.3: Non-RF Fabric-enabled Communications
- Theme 5.4: Enabling Novel Lightwave Capabilities for the Soldier

One project in SRA-5 that has received much attention regards a new method for tailoring the wavelength of light so that it better matches the regime that can be converted to electricity by a photovoltaic cell. ISN research engineer Ivan Celanovic, working with a multidisciplinary team of MIT faculty and researchers, has coated a specially designed microreactor with a layer of nanostructured photonic crystal. This crystal effectively suppresses emissions at non-ideal wavelengths while enhancing those at ideal wavelengths, resulting in a more effective conversion of light to electricity. Ultimately, this small system could result in a power supply that is many times more efficient than the standard lithium-ion batteries used in many types of electronic devices.

Government Collaboration

Army 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 has had substantial interactions with the following Army science and technology laboratories and centers:

- Army Research Laboratory
- Aviation and Missile Research, Development, and Engineering Center
- Communications-Electronics Research, Development, and Engineering Center
- Edgewood Chemical Biological Center
- Natick Soldier Research, Development, and Engineering Center
- Picatinny Armament Research, Development, and Engineering Center
- Tank Automotive Research, Development, and Engineering Center
- Army Corps of Engineers
- Walter Reed Army Institute of Research
- Walter Reed Army Medical Center.

And ISN has had interactions with the following U.S. government entities:

- Camp Roberts
- Naval Postgraduate School
- Naval Sea Systems Command
- US Air Force
- US Department of Agriculture
- US Food and Drug Administration
- US Special Operations Command

Industrial Collaboration

Industry partners are critical to the ISN mission, helping to turn laboratory innovations into real products and to scale up those innovations for affordable manufacture in quantity. The past year has seen the addition of three companies to the ISN Industry Consortium—QD Vision, Total American Services, and Xtalic. Additionally, ICx Technologies was acquired by FLIR Systems, which took ICx's place as an ISN industry partner. The following are ISN industrial partners:

- Battelle
- CIMIT (Center for the Integration of Medicine and Innovative Technology)
- Dow Corning
- DuPont
- FLIR Systems
- W. L. Gore and Associates
- Honeywell
- JEOL USA
- Mine Safety Appliances

- Nano-C
- Northrop Grumman
- QD Vision
- QinetiQ North America
- Raytheon
- Total American Services
- Triton Systems
- Xtalic

Soldier Design Competition

The MIT Soldier Design Competition (SDC) completed its eighth year. The objective of the competition is to provide an engineering design and prototype building experience for undergraduates that will address real technology problems faced by modern soldiers and first responders. Cadets from the U.S. Military Academy (USMA) at West Point joined the competition in its second year, with several participating as part of their capstone engineering design project. USMA cadets have continued to participate in SDC, and more than 275 undergraduates and cadets have entered the competition thus far.

SDC projects during the past year included a design for safely airdropping packaged water without need for a parachute, renewable power generators for use at remote bases or outposts, and a handheld tracker for the dismounted soldier, among others. Some participants proposed their own challenges and responding inventions in an open design category, designing and building such items as a power-assisted lower body exoskeleton and a thin-film battery integrated into the form factor of a standard US flag patch.

Teams compete for prize money provided by industry sponsors, and there is a final judging by senior personnel from industry, the Army, and academia. In the finals of the eighth SDS, held April 27, 2011, prize-winning inventions included a modified Hesco-style barrier that can be deployed and filled more rapidly than a standard version, and a portable, modular wind-powered generator.

Competition participants own the intellectual property rights to their inventions and are encouraged to pursue patents and commercialization. To that end, SDC alumni have founded a total of 13 companies and transitioned technology for practical applications.

ISN continues to host SDC on an annual basis, with the 2011–2012 competition finals scheduled for April 25, 2012.

Summer Intern Research Program

In summer 2008, working with Army colleagues and under the leadership of professor Christine Ortiz, ISN began a summer internship program to provide MIT students with opportunities to perform research at Army laboratories under the guidance of

Army scientists. Professor Ortiz continues to champion the ISN/Army Labs Summer Intern Research Program, with assistance from Marlisha McDaniels of the ISN headquarters team.

For the summer 2011 program, over 70 students showed interest and 12 of those students, from seven MIT departments, have been chosen to work at five Army laboratories. Over 30 Army scientists showed interested in mentoring and signed up on the ISN online system, allowing them to post internship opportunities for viewing by students and allowing interested students to post their CVs for viewing by Army scientists.

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 basic research projects at HBCU-MIs and facilitates collaborations between HBCU-MIs and ISN scientists. Also, visiting faculty and students from HBCU-MIs utilize ISN research facilities.

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 480 registered users from 14 MIT departments, laboratories, and centers have access to ISN facilities, which include wet and dry laboratories, computer clusters, and research instrumentation, including equipment for electron microscopy and femtosecond laser spectroscopy. Additionally, beginning in 2006, ISN has provided more than $3M in seed and augmentation funding for a total of 18 projects involving 22 faculty and staff from nine departments, laboratories, and centers.

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 partnering with the Army and industry and to enrich its portfolio of basic research by involving a number of new faculty. 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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