Institute for Soldier Nanotechnologies

Founded in 2002, the Institute for Soldier Nanotechnologies (ISN) is a three-part 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 an integrated system of nanotechnologies that combine high-tech protection and survivability capabilities with low weight and increased comfort.

Army funding for ISN basic research is approximately $100 million over 10 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 Army leaders, the ISN was approved for the renewal of its five-year contract. ISN-3 will begin on August 1, 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 200 refereed publications in journals such as *Advanced Materials*, *Nature*, *Nature Materials*, *Nature Nanotechnology*, and the *Proceedings of the National Academy of Sciences*. Additionally, typically 700 to 800 people visit the ISN annually for briefings on research endeavors and tours of ISN facilities. On March 16, 2012, the ISN was privileged to host the Secretary of the Army, the Honorable John McHugh, who was accompanied by the Deputy Assistant Secretary of the Army for Research and Technology, Marilyn Freeman.

Research

The ISN's signature interdisciplinary research agenda evolved over the course of its first 10 years into a focused program reflecting the areas where the ISN and the Army see the potential for especially strong soldier impacts. This structure will remain substantially intact for the third contract, which will be enacted on August 1, 2012, though specific areas will be repositioned and redefined to better align with and more efficiently respond to Army needs. Team-based innovations are a hallmark of the 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 nano-scale and nano-structured 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 nano-structures.

- 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 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 & Long-Term Treatment of Battlefield Injuries

Strategic Research Area 3: Multiple Blast & 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 can 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, explosives, and 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, & Explosives Using Integrated Nano-structured Platforms
- Theme 4.2 – Quantum Dots for Chemical/Biological Sensing

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

The goal of SRA5 is the integration of nano-scale 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; 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 Battlesuit Functionality and Protection

Transitioning

The ISN places a strong emphasis on basic research. However, the transitioning of promising research outcomes is an equally crucial component of our mission. To this end, 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 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, 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 startup company OmniGuide of Cambridge, MA, and is being used in hundreds of 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 of Portland, OR, 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 the nanoscale, the 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 and Picatinny Armament Research, Development, and Engineering Center, and to MIT startup Xtalic of Marlborough, MA, 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. The 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 the world's most realistic human head and helmet model in order to explore the effect of blast wave impact (e.g., from improvised explosive devices) 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 in mice, 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 over five months.

Along a different direction is the development of rapid reconstitution packages (RRPs) of lyophilized drugs to enable greatly simplified logistics, dramatically prolonged drug shelf life, and increased ease of administration in the field.

Wireless Power

While this 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 of Watertown, MA, 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 (REF), in collaboration with ISN partner QinetiQ North America of McLean, VA, is researching the remote charging of robots. Recent WiTricity advances that enable the transfer of 3.3kW over a distance of ½ meter at over 90% efficiency have opened the possibility of the cordless charging of electric vehicles.

Nano-particles and Quantum Dots

Colloidal quantum dot nanoparticles produced through low-cost polymer processing are enabling a wide range of new capabilities in situational awareness. ISN partner company Raytheon of Waltham, MA, in collaboration with the Army's Night Vision and Electronic Sensors Directorate (NVESD) and the Army Research Laboratory-Sensors and Electron Devices Directorate (ARL-SEDD), is transitioning these particles for low cost, room temperature infrared sensing for night vision and for simultaneous detection of IR and ultraviolet light with one device to enable day- and night-time communications. ISN partner company QD Vision of Lexington, MA, working with the Army Research Laboratory-Weapons and Materials Research Directorate (ARL-WMRD) and ARL-SEDD, is transitioning quantum dots that sense in the short wave IR spectral window to provide technology that will tag, track, and locate objects and people using a single marker that can be identified in both night and day.

Gentle CVD

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 that one can use as the substrate and the depositant. Gentle CVD, pioneered by ISN faculty, enables the deposition of thin (nanometer to micrometer, conformal coatings of heat- and chemically-sensitive polymers and hybrid structures on diverse substrates. Startup company GVD in Cambridge, MA, 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 foodborne pathogens.

Historically Black Colleges and Universities and Minority Institutions Program

In 2007, with professor Paula Hammond as program director, the 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 Collaborations

While the ISN's first customer remains the soldier, many research projects have broad appeal to not only the Department of Defense (DoD) but also other government agencies. ISN 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 industrial quantities. Two companies joined the ISN Consortium in the past year. The ISN is proud to welcome Nike, Inc. and VF Corporation. Current membership of the ISN Industry Consortium includes:

- Center for Integration of Medicine and Innovative Technology (CIMIT) in Boston and Cambidge, MA
- Dow Corning in Midland, MI
- DuPont in Wilmington, DE
- FLIR Systems in Portland, OR
- General Atomics in San Diego, CA
- W.L. Gore and Associates in Newark, DE
- Honeywell in Morris Township, NJ
- JEOL USA in Peabody, MA
- Mine Safety Appliances in Cranberry Township, PA
- Nano-C in Westwood, MA
- Nike in Beaverton, OR
- Northrop Grumman in Falls Church, VA
- QD Vision of Lexington, MA
- QinetiQ North America in McLean, VA
- Raytheon of Waltham, MA
- Total American Services in Houston, MA
- Triton Systems in Chelmsford, MA
- VF Corporation in Greensboro, NC
- Xtalic in Marlborough, MA

Outreach Activities

Soldier Design Competition

The ISN Soldier Design Competition (SDC) was established in 2003 to engage MIT undergraduates in the activities of the ISN. In 2004 it was expanded to include cadets from the United States Military Academy at West Point. 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 industrial sponsors that have included Boeing of Chicago, IL; General Dynamics of Falls Church, VA; L-3 Communications in New York, NY; Lockheed Martin in Bethesda, MD; 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 Army and Marine Corps Science and Technology, Acquisition, and Operations Communities. SDC participants meet active duty soldiers and marines, and develop perspectives on how modern technology can help the US 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 prototypes. Competitors also own their own intellectual property, and are encouraged to further develop and commercialize their inventions.

Army Nanotechnology Seminar Presentations

One of the ISN's premier outreach endeavors, 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 monthly seminars also offer ISN researchers, graduate students, and post-doctoral associates the opportunity to learn more about research underway at Army labs and other facilities.

To help our colleagues at other locations participate, ANTS sessions are webcast using a collaboration software that facilitates real-time interaction. Remote participants can watch and listen to presentations, and engage in Q&A.

ISN-Army Labs Summer Internships

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

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

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

ISN Industry Collaboration Portal

Over the past year, the ISN has developed and implemented an industry collaboration portal, an 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, with these updates announced to ISN Consortium points of contact, ISN faculty, and Army members of Team ISN via email.

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 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, the ISN has provided more than $3 million in seed and augmentation funding.

Future Plans

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

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