Institute for Soldier Nanotechnologies

Created in 2002, the Institute for Soldier Nanotechnologies (ISN) was recently awarded its second five-year contract by the US Army Research Office.

A three-member team designed to leverage the unique capabilities of the US Army, industry, and MIT, the ISN mission is to provide a dramatic increase in survivability to the individual Soldier through nanoengineered materials and devices incorporated within a lighter-weight uniform. 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 create a sleek 21st century battlesuit that combines high-tech capabilities with light weight and increased comfort.

Research

ISN's signature interdisciplinary research agenda evolved over the course its first five years into a more focused program, reflecting the areas where ISN leadership and the Army see contributions emerging, and the renewed contract finds 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 distinct Strategic Research Areas (SRAs) that are, in turn, split into themes and specific projects.

Strategic Research Area 1: Lightweight, Multifunctional Nanostructured Materials

ISN's exploration into the development of multifunctional fibers and constructs takes many forms, encompassing a total of six themes and eight projects 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 nano-scale coatings, core-shell and rod-rod nanostructures, carbon nanotubes, fibers, fabrics, layered and membrane structures.

Theme 1.1—Surface Active Multifunctional Fibers and Fabrics

The overarching goal of Theme 1.1 is to develop the fundamental nanotechnology of fibers, fabrics and related textiles and membranes, leading to the discovery and development of novel materials for soldier protection, survivability and comfort through surface activity. Surface functionalization of textiles using layers of nanoscale thickness imparts virtually no weight to the garment but adds the capability to introduce controlled activity towards specific threats, such as the environment, chemical or biological weapons, and other mad-made exposure threats. The ISN possesses the capability to produce fibers from conventional size down to nanofibers. Processes to control fiber size, composition, and morphology were previously explored and developed in the ISN Nanofoundries. Methods to self-assemble or to post-treat such fibers to acquire targeted functionality are exemplified by the potential for designer chemistries developed within the ISN, and by advances in chemical vapor deposition and layer-by-layer treatments. The resulting materials will provide specific capabilities that enhance the battle suit in its purpose to serve and protect the soldier.

Theme 1.2—Smart Quantum Dots: Microfluidic Fabrication, Detection, and Sensing

The focus materials of Theme 1.2 are semiconductor nanocrystal quantum dots (QDs). The overall goal of this theme is to design, develop, assemble, and incorporate QD structures as a nanotechnology with impact in opto-electronics and molecular sensing. Nanocrystal quantum dots are nanosize particles of semiconductors whose properties are strongly dependent on their size, composition and morphology. Quantum dot heterostructures form junctions at the nanometer scale that impart further flexibility in the design of their electrical, optical, and chemical properties. Their applications in optoelectronics and their compatibility with both organic and inorganic electronic materials can lead to light weight, nanometer thin, large area, flexible, solution processable device structures such as photodetectors, light emitters, and memory devices that can be networked and incorporated into a soldier's situational awareness tools for improving survivability. Quantum dots can also be used as fluorescent reporters of local nanoscale environments, and coupled with appropriate chemistry can be integrated as reversible sensors of their molecular environment, with application in biomedical monitoring or chem-bio threat detection. The proposed portfolio of complementary projects explores three aspects of quantum dot nanotechnology: (1) A novel high temperature and high pressure microfluidic synthetic platform for exploring the fabrication of novel complex QD structures, (2) The integration of QDs as the active element in thin, large area photodetectors for the visible and infrared, and (3) The development of QD fluorescence reporters in reversible, self-referencing molecular sensor.

Theme 1.3—Imaging and Sensing with Carbon-Nanotube Devices

Inexpensive, robust, and low-power optical and chemical multifunctional sensors will greatly enhance the capability of a soldier to identify potential threats, alerting them of unexpected chemical threats, or allowing to integrate inconspicuously night-time vision capabilities, or friend-or-foe recognition. Theme 1.3 is dedicated to developing the science and technology needed to create such working multifunctional devices, based on an integrated carbon nanotube platform. Carbon nanotubes are one of the most promising nanomaterials ever developed, light weight and with exceptional mechanical and thermal resilience, electrical and heat conductance. Their structure and geometry are ideal for imaging and detection, because they are essentially a conducting surface rolled into a nanoscale active wire. Chemical functionalizations offer a powerful route to build multiple capabilities on nanotube arrays and to tune and target the nanotube's electrical response, from photocurrents to conductance modulation. Our projects borrow from the microelectronics industry a vertical-growth paradigm to allow large-scale processing strategies for carbon nanotubes and integration on a single chip. On this versatile platform, wet chemistry will offer the capability to build, inexpensively, complex monitoring capabilities into a large numbers of devices.

Theme 1.4—Multimaterial Multifunctional Fibers

The overall goal of this theme is the development of the multimaterial multifunctional fiber devices. Virtually all electronic and optoelectronic devices necessitate the prescribed assembly of conducting, semiconducting and insulating materials into specific geometries with intimate interfaces and microscopic feature dimensions. While a variety of wafer-based processes have been developed to deliver these requirements, all are inherently restricted by the wafer size, its planar geometry and the costs associated with the large number of consecutive high precision processing steps. In contrast, the technique of optical fiber drawing from a macroscopic preformed rod is simpler and yields extended lengths of highly uniform fibers, so far, this technique has been restricted primarily to insulating materials, simple geometries and large features. Recently, a new family of fibers composed of conductors, semiconductors and insulator has emerged. These fibers while sharing the basic device attributes are fabricated using conventional fiber processing approaches thus yielding kilometers of functional fiber devices. Under this theme we will be focusing on the development of a canonical set of unifunctional fiber devices including: wavelength-scalable hollow-core transmission fibers; Fabry Perot fiber resonators; transverse surface emitting fiber lasers; thermal and optical fiber detectors and piezoelectric fibers. While each device presents unique materials selection and processing challenges there are significant overlapping issues that unite these two research objectives. One of the common challenges is that of electrical activation. To that end we will need to provide continuous electrical contacts running through the entire fiber forming intimate contact with the active medium. Since metallic elements are crystalline they will undergo a phase transition and thus will form a low viscosity liquid during the fiber draw process. This in turn will generate ample opportunity for capillary breakup. The conditions and structures that lead to the preservation of cross section from the preform to drawn fiber will be elucidated. Future improvements in fiber materials and additional geometric and feature control will enable the delivery of semiconductor device functionality at fiber optic length uniformity and cost and present significant opportunities for fabrics with system level sophistication to be developed under Theme 5.2.

Theme 1.5—Functional and Responsive Elastomers

For applications such as actuable membranes for temperature management and chemical/biological agent protection, high strength, high strain polymeric materials for tough smart fabrics and heat, light, or chemistry-responsive fibers, the use of a true, high strength elastomeric fiber with the ability to undergo direct tensile or contractile response is critical. In general, there is a performance gap between rigid, high strength materials that cannot undergo significant mechanical strain, and responsive polymer gels or materials that can undergo actuation or shape response but often at the cost of maintaining strength and toughness. The strategic approach in this theme is the development of new elastomeric materials that can undergo shape change, deformation, expansion or changes in stiffness or damping/compliance on exposure to light, electrical field, environmental temperature changes, and potentially even the presence of different chemical agents. The approach entails both a strong synthetic component for the creation of new functional materials with field-responsive side or main chains, as well as the generation of nanocomposite blends with these new materials and inorganic nanoparticles. Interesting concepts include the possible coupling of nanoparticle chemistries with elastomer side groups such that mechanical properties can be reversibly modified in the presence of different chemicals, or the use of electrochemically activated particles that yield actuable membranes that open or close on demand.

Theme 1.6—Nanostructured Materials for Simultaneous Control of Light and Sound

Theme 1.6 involves one project, summarized below, and the efforts of two faculty members. Strategically, this Theme is concerned with learning how to build-in multi-functional nano-scale enabled properties in periodic composites and other materials capable of also providing lightweight and robustness. An example, proposed here for systematic study, is co-location of complete electromagnetic and elastic band gaps in periodic composite materials. This would allow the flow of light and sound through the material to be simultaneously regulated. The research approach combines modeling and simulation studies with experimental investigations. The former will study the interactions of electromagnetic and elastic waves with each other and with high order materials characterized by 3D nano-scale periodic structures. Experiments will test modeling predictions, and prove the core concept of synergistic photon-phonon interactions enabled by nanostructures. Further capitalizing on modeling results, experiments will be used to design, process and test promising photonic/phononic band gap materials. Potential applications to Soldier survivability include communications, thermal protection, and improved thermoelectric devices for power generation or cooling.

Strategic Research Area 2: Battle Suit Medicine

This SRA 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 on the battlefield. In the longer term, technologies based on the basic research of SRA-2 would be incorporated in the multi-capability battlesuit. These technologies could be activated by: qualified medical personnel (nearby or remotely located, e.g. via suitably protected telemetering), by the Soldier in the field, and even autonomously, 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 MEMs-based device to prevent hemorrhagic shock. As shown in the following list, the research in this SRA is divided up among three themes and seven research projects.

Theme 2.1—Nanostructured Actuators: First Principles to Fabrication

The overall goal of Theme 2.1 is to develop a lightweight polymer actuator exhibiting high power density, large and fast contraction capabilities and high strength. This actuator technology is at the center of the design of a multifunctional soldier armored actuation system protecting and enhancing the performance of the soldier in the battlefield. Our aim is to design, model, synthesize and study novel polymer nanoscopic architectures to produce these actuators with superior performance relative to non-structured bulk actuator materials. These novel materials are based upon a combination of groundbreaking conducting polymer molecular architectures (Swager Laboratory), innovative manufacturing and processing techniques (Thomas and Hunter Groups), advanced quantum mechanical modeling (Marzari Group) and novel development of instruments for extended actuator characterization (Hunter Group). Previously, within the framework of the ISN supported project we have successfully created active materials generating 100 times more force per unit cross section than human skeletal muscle. Making use of our pioneering work and unusual approach from first principle modeling to fabrication, our ambitious yet achievable objectives within this theme are to create enabling contractile materials for an active battle suit within three years.

Theme 2.2—Functional and Responsive Nanostructured Surfaces

The objective of Theme 2.2 is to design a new generation of responsive surfaces that are able to deliver a range of therapeutic drugs, vaccines, or remediatory elements to the soldier to alleviate or prevent disease and promote healing of injuries and wound to provide medical care to the soldier on the battlefield rapidly and conveniently. The needs that will be addressed include: the development of wound dressings, fabrics and surfaces that contain highly potent antibacterial agents which are not susceptible to the development of resistant bacterial strains and can be released over highly sustained and controlled periods of time; the incorporation of specific and timed sequences of multiple therapeutics such as antibacterials, anti-inflammatories, and tissue healing growth proteins in unique thin film wound healing scaffolds and dressings; and the ability to generate and store large quantities of vaccines for long time durations in lightweight flexible thin films that could be administered orally, transdermally, or subdermally. The methods used to generate these surfaces are a particularly synergistic combination of bio-informatics, genetic engineering, nanostructured materials design and synthesis, and polyelectrolyte multilayer thin film nanoscale-assembly techniques developed at MIT. Both of these projects described below are new to the ISN, and introduce entirely new methods and approaches to the important area of battlefield medicine.

Theme 2.3—Non-invasive Medical Monitoring and Drug Delivery

Theme 2.3 seeks to dramatically improve soldier survivability from a diverse array of threats through integration of microsystems for physiological monitoring and autonomous response. This strategy could ultimately prove simpler than requiring a sensor for each threat or developing and adding additional sensors as new threats arise. Indeed, it may not always be possible to have a direct sensor of a chemical or biological threat. For this reason and many others, physiological monitoring of small, non-invasively obtained samples of bodily fluids will be a critical component of future battlesuits. Secondly, autonomous administration of active agents in response to threats is an additional revolutionary feature of the future battlesuit. Miniaturization achieved by MEMS technology would allow the monitoring and response system to be carried by the soldier or integrated directly into the battlesuit. Autonomous operation is essential since the soldier may be incapacitated on the battlefield. This theme also includes research to provide a light weight, low electric power consumption means to drive microfluidic devices that will allow rapid real-time monitoring of a soldier's exposure to environmental toxins, including chemical and biological hazards.

Strategic Research Area 3: Blast and Ballistic Protection

SRA 3 will concentrate research from 14 faculty members on the critically important strategic Soldier capabilities of blast protection and ballistic protection. Recognizing the importance of blast related Soldier injuries in current operations, we are increasing the ISN's efforts in blast protection. This will complement and indeed enrich our ballistic protection research. In particular, SRA-3 will direct considerable assets towards understanding blast interactions with materials including human (brain) tissue as well as various anthropogenic energy absorbing structures including microframe structures that contain nano-trusses. As shown in the following list, this SRA features three themes encompassing five projects.

Theme 3.1—Lightweight Nano-architectures for Ultra-strong Energy Absorbing Materials

Theme 3.1 involves three projects summarized below. The unifying thrust of this theme is careful study of a range of different materials that are of interest for providing light weight and very high mechanicals strength. These materials include stiff chain polymers based on iptycene and related monomers that incorporate pendant groups at strategic sites along the polymer axis. These polymers provide different mechanisms for absorbing mechanical energy while accommodating appreciable deformation without structural failure. Another project will study the formulation and mechanical deformation behavior of microframe structures with 100 nm size features, that show promise for providing low density and champion resistance to ballistic and blast insults. This theme will also include studies of naturally occurring nanostructured materials to establish design laws to guide fabrication of man made nanocomposites that will exhibit high strength and toughness.

Theme 3.2—Materials and Structures for Blast Protection and Injury Mitigation

Theme 3.2 involves just one project, summarized below, but the efforts of 6 faculty members. Strategically, this theme is concerned with bringing together a critical mass of research experience to confront the serious problem of blast-induced Soldier injury. In particular, this theme marshals basic research expertise on high strength materials, including materials components, structures and systems, mechanical testing and materials failure mechanisms, blast wave interactions with complex materials, including human tissues, and ultra fast optical diagnostics of shock propagation and shock-induced damage in solids. Research tools include experimental studies as well as modeling and simulation. Soldier benefits will be new fundamental understanding: (a) to inform the design of lightweight materials and structures to provide superior blast protection, and (b) to illuminate means to prevent blast-induced injury to humans and structures.

Theme 3.3—Lightweight Nanocrystalline Alloy Fibers for Blast Protection

Theme 3.3 involves just one project, summarized below, and the efforts of three faculty members. Strategically, this theme opens up to the ISN a systematic basic research investigation of a different category of materials of interest for blast and ballistic protection. These materials are low-density metal alloys, that could be fabricated into lightweight and flexible assemblies such as truss-like structures and woven arrays that could function effectively as comfortable body armor. This theme marshals complementary research assets, i.e., experimental expertise to devise novel alloy structures and modeling/simulation capabilities to shed light on how alloy structure can be tailored to provide desired ballistic and blast resistant properties such as combining high mechanical strength with lightweight.

Strategic Research Area 4: Chem/Bio Detection and Protection

This SRA is concerned with research to provide new scientific and engineering understanding to enable the detection of hazardous substances in the environment as well as 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 theme focuses on different means to obtain nano-scale polymeric coatings that provide specific protective functionalities. Another thrust concentrates on different approaches to the sensing and characterization of various materials, including toxic substances that exhibit identifiable chemical signatures. A third activity seeks to develop the understanding needed to manufacture multi-layered 3D nano-structures from foldable 2D nano-patterned surfaces. Potential applications include ability to scaffold and integrate multiple threat detection capabilities in lightweight and low-energy consumption platforms. As shown in the following list the research in this SRA is divided up among three themes and seven research projects.

Theme 4.1—Multifunctional and Switchable Surfaces for Protection and Survivability

The overall goal of Theme 4.1 is to invent, develop, validate, exploit, and mechanistically explore novel polymeric nanocoatings for soldier protection, survivability and comfort. Surface functionalization of textiles using layers of nanoscale thickness imparts virtually no weight to the garment but adds the capability to control surface hydrophobicity/hydrophilicity and to mitigate chemical and biological threats. Integration of functional and switchable nanocoatings into biosensors is essential for detecting toxins in the battlefield in a sensitive and portable manner and thus offering a method of improving soldier survivability. The proposed portfolio of complementary vapor phase and solution processing creates a broad range of synthetic possibilities. For instance, chemical vapor deposition (CVD) is well suited to the formation of insoluble coatings while deposition of polyelectrolyte films is easiest to achieve by solution methods, such as layer-by-layer (LBL) techniques. Previously, an ISN-supported collaboration has demonstrated that vapor phase and solution phase synthetic platforms can be integrated to create multifunctional coatings, such as surfaces that are both hydrophobic and antimicrobial [J Lin J, SK Murthy, BD Olsen, KK Gleason, AM Klibanov, Biotechnology Letters. 25, 1661 (2003)].

Theme 4.2—Ultrasensitive Nanoengineered Chemical Detectors

This theme focuses on research to develop different approaches to sensing and characterization of materials, including toxins, with identifiable chemical signatures. Each project exploits manipulation of nano-scale features of materials to achieve specificity, spatial resolution, convenience of use, reduced power demand, or multi-functionality. For example, research in this theme seeks to develop a fluorescence microscope that will provide specificity in chemical mapping of surfaces down to a lateral resolution of 5 nm. Another project seeks to lower the cost of large-area multi-spectral infrared technology, including IR digital cameras. Potential applications are identification technology, simultaneous viewing of visible and IR light, muzzle flash determination, and chem./bio detection. A third project seeks to nano-engineer zero power demand crystals to detect specific vapors by a simple color change. These crystals could thus be delivered to suspect areas and warn the Soldier of hazardous substances without the need to enter the contaminated region.

Theme 4.3 Overview—Nanostructured Origami

The overall goal of Theme 4.3 is to develop the science and technology necessary to realize the Nanostructured Origami™ 3D Fabrication and Assembly Process, a method of manufacturing multi-layered (3D) nano-systems from foldable nanopatterned surfaces (2D). This method has already been successfully demonstrated with ISN funding [W. Arora, et al, Appl. Phys. Lett. 88:053108, 2006] The final 3D configuration is obtained by first nanopatterning a functional 2D membrane and subsequently folding selected sections of the membrane sequentially in a pre-determined order. Since the nanopatterning step is on a surface, standard lithographic techniques from the semiconductor industry can be employed, as well as more recently invented nanopatterning methods including nano-imprint lithography. Nanostructured Origami™ allows complex geometries to be formed in addition to multi-layered devices, and it allows such devices to be formed in a single step, bypassing the processing difficulties associated with 3D nanostructures. The Nanostructured Origami™ process is also well suited to the hybrid integration of modalities (chemical, biological, electrical, optical, mechanical, etc.) which is a key enabling technology in numerous chemical and biological sensing and threat detection systems that are lightweight, low-cost and low-energy-consumption and thus portable to the battlefield.

Strategic Research Area 5: Nanosystems Integration

Systems of components that contain nano-scale materials and devices can enable powerful protection and survivability capabilities for the Soldier. This SRA is concerned with research to create or exploit such nano-scale materials and devices and to understand their behavior within capability-enabling systems. One focus of SRA-5 is nanoelectromechanical devices, e.g., high performance complementary field effect transistors containing polymer nanowires and resistivity-based chemical sensors. Another study concentrates on realizing integrated systems level performance from metal-insulator-semiconductor fibers originated at MIT. This work will address two different systems length scales: the sub-micron scale to fathom integration limits for a single fiber, e.g., what type and number of functionalities can be combined in one fiber; and the macro scale, ca 1 meter, to illuminate what types of sophisticated functionalities can be obtained by capitalizing on the fact that 102-106 fibers can be combined in a fabric or other structure. Another SRA-5 theme will seek the understanding needed to develop non-RF, fabric-enabled communications, including a laser-to-uniform communications system that works in free space. Important research questions include behavior of the multi-material optical fibers that will enable this system, response time, sensitivity and noise management in the photodetectors, incorporation of the fibers into a larger fabric, hardware and software needs to effectively interface receivers to a data acquisition system, and the fidelity of information transmission and recovery. Another study will examine the use of nano-structured materials to enable, for the first time, observable optical nonlinear responses at very low power levels. Of interest are light-light interactions that enable access to frequency regimes that are difficult to reach with existing laser sources. Soldier applications include remote sensing of the environment and eye protection. As shown in the following list the research in SRA-5 is divided up among four themes each involving one research project.

Theme 5.1—Nanoelectronics

Complex technologies smooth and complete integration with the highest possible speed and integration density, but with increased functionality, an ability to integrate heterogeneous materials, and a priority on power efficiency. The proposed portfolio includes nanoelectromechanical devices that exhibit higher transconductance than conventional transistors, thereby lowering power dissipation in memories and transistors. In addition, many battle suit applications necessitate the use of flexible substrates that cannot support high temperature processing. For these applications, we propose high performance field effect transistors with polymer-carbon nanotube composite channels. Finally, we propose a battlesuit integration platform for chemical sensors, thereby enhancing the functionality of the battlesuit. The common theme of the portfolio is the exploitation of uniquely nanoscale phenomena with an emphasis on functional devices.

Theme 5.2—Integrated Fiber and Fabric Systems

The modern soldier faces an ever- increasing number of threats, which can emerge from all directions and engage him anywhere on his body. Fortunately, prior to the actual engagement an adversary will typically emit a non-voluntary warning signal that in principle can be detected. The ability to protect a soldier or vehicle depends on our capability to detect and process these early warning signals at speeds that exceed milliseconds. Adding to the dimension of this challenge is the fact that these warning signals involve a wide array of basic physical excitations: electromagnetic, acoustic and even thermal. For example: an electromagnetic wave in the visible regime emitted from the rocket launcher precedes the impact of an RPG, thus in principle identifying it's source and enabling counter measures. An acoustic wave from a stray bullet may provide information on the sniper location. A laser range finder or laser designator beam will probe prior to the tank shell. The acoustic wave associated with a hollow charge impacting a vehicle precedes the damage associated with the charge detonation and penetration and may, in principle, allow for the deployment of a directed countermeasure. The large area detection requirements, speed of detection, and diversity of excitation types, necessitate new multifunctional detection paradigms. To do so we will build on the recent discovery of multimaterial functional fibers at MIT that will be developed under theme 1.4. The key enabling feature of these new fibers is their ability to cover and impart functionality to very large areas commensurate with the entire surface of a dismounted soldier or motorized vehicle or aircraft. The objective of this research theme will be the development of paradigms for the realization of integrated system level performance using MIT's unique metal-insulator-semiconductor fiber platform. These will encompass two completely distinct length scales, each of which defines new frontiers in fiber research: On the one hand, the microscopic sub-micron length scale, where the limits of integration on a single fiber level will be studied; with questions such as: what type and number of functional elements can be combined in a single fiber? On the other hand, the macroscopic meter scale, where the implications of combining multimaterial functional fibers into large assemblies or fabrics will be examined; with questions such as: what types of sophisticated functionalities can be achieved given that 102-106 fibers are combined in a fabric or other geometric construct? The research will explore the tradeoffs between the sophistication of a single fiber vs. the complexity of the fiber assembly for achieving particular overall system functionality specifications. The types of system-level functions that will be possible are intimately related to the types of fiber devices developed under project 1.4.

Theme 5.3—Non-RF Fabric-enabled Communications

The ability to quarry at the speed of light specific assets including fellow soldier on the battlefield, positively identify them and even direct communications to them without compromising target acquisition are all enabled by free space line of sight optical communications. And while direct visualization has been, and always will remain the primary source of information collection and target acquisition there is currently no efficient high-bandwidth method to directly quarry or communicate with observed objects on the battlefield. Ad-hoc free space optical communications addresses this deficiency, in particular in dense urban operations situations where the combination of RF jamming devices and various interference mechanisms (MPI) wreak havoc on RF communications and RF positioning devices. This theme will present a unique and elegant solution to the problem of large area optical detection and thus will enable pervasive combat "laser to uniform" communications. For the first time the entire uniform or surface area of a vehicle will become a functioning optical receiver. At the heart of our approach is the development of a fabric that is at the same time a sensitive optical receiver. The objective of this project will be to develop the fiber detector materials, integrate them into a fabric, and design the electrical interface and communications system. The "laser-to-uniform" communications system that we propose will take voice spoken into a microphone and convert it to an optical signal embedded on a laser beam. This signal will be sent by directing the laser beam at the recipient's uniform. The signal will be received by a soldier's uniform and then converted to audio. The "laser to uniform" communications system will result in high fidelity communications even with partially obscured sources. This system will enable line of sight communications at distances that far exceed shouting and thus can be operated covertly. Of particular interest is the ability to integrate this system with UAV's, which would allow the commander to combine direct feed optical imaging information with directed optical communications.

Theme 5.4—Enabling Optical Nonlinear Capabilities for the Soldier

The overall goal of Theme 5.4 is to explore the potential of using nanostructured materials to enable, for the first time, observable optical nonlinear response at very low power levels. Inducing an optical nonlinear response in a material system leads to a very powerful physical tool: without this response, it is impossible to have one light signal influence another. For example, optical nonlinearities are the only way to implement all-optical signal processing, and hence eventual all-optical quantum information processing and quantum encryption. Moreover, when light interacts with light, drastically new frequencies can be created. This enables access to frequency regimes that are very difficult to reach with existing laser sources. Having coherent transportable sources at many different wavelengths would supply the soldier with an unprecedented tool for remote sensing of the environment. Finally, strongly nonlinear optical materials could be used to protect the eyes of the dismounted soldier against harmfulintensity radiation-weapons. Unfortunately, in naturally occurring materials, optical nonlinearities are extremely weak. This means that in order to explore or even observe these nonlinearities, one has to use very high power sources; such systems are typically bulky, expensive, and completely impractical to transport or operate, especially in battle conditions. Therefore, the use of optical nonlinearities for soldier-related applications has, thus far, been very limited. The current theme is focused on exploring the possibility that the nanostructuring of materials, at length scales smaller than the wavelength of light of interest, could dramatically enhance optical nonlinearities, so they could be used at much lower power levels. Successful outcome of this prospect would be an enabling platform for exploration of optical nonlinearities for a wide range of important soldier-related applications.

Industrial Collaboration

Industry partners are critical to the ISN mission because of the need to turn laboratory innovations into real products and scale them up for affordable manufacture at needed throughputs. The ISN Industry Consortium currently stands at 14 members:

- Battelle
- Dow Corning
- DuPont
- Foster-Miller
- Honeywell
- ICx-Nomadics
- JEOL USA
- Mine Safety Appliances
- Nano-C
- Northrop Grumman
- Raytheon
- Partners Healthcare
- Triton Systems
- W.L. Gore and Associates

It is the intent of the Army to make available for competition on an annual basis funding to assist ISN industry partners in performing applied research and development to transition promising ISN basic research results into practical products for the soldier.

Soldier Design Competition

The MIT Soldier Design Competition continued into its fifth year. The objective of the competition is to provide an engineering design experience for undergraduates that will address real technology problems faced by modern soldiers and first responders. USMA cadets joined the competition during its second year, several participating as part of their capstone engineering design course and working on the same challenges as the MIT teams, and continued with great success in the third competition. Fifth-year challenges included a collision avoidance system for small unmanned aerial systems, a soldier virtual mission planner for training and rehearsing mission scenarios, and an integrated beacon/tracking device for search and rescue operations, among others. Participants could also propose their own challenge and responding invention in an open design category.

Competition participants own the intellectual property rights to their inventions and are encouraged to pursue patents and commercialization. To that end, several SDC alumni have taken their inventions forward. Most notably, Team ATLAS has formed a company around their design for powered rope ascender. Team Surreptiles, now incorporated as RallyPoint, has further developed its novel gloved-based computer input device, has been incorporated into the Army's Future Force Warrior program, and has received a three-year contract with DARPA.

ISN continues the Soldier Design Competition on an annual basis, with the 2008–2009 Competition Finals scheduled for April 16, 2009.

Future Plans

ISN's mission remains extremely relevant to current national priorities, and it is expected that key research directions will continue and new research themes will be added.

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More information about the Institute for Soldier Nanotechnologies can be found at http://web.mit.edu/isn/.