Scott Aaronson, University of Texas, Austin

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Paths to Quantum Supremacy

In a project that will bridge abstract theoretical computer science with near-term experiments, Professor Aaronson will investigate how to achieve "quantum supremacy"---that is, a clear quantum computing speedup over the best-known classical algorithms ---with the quantum devices expected to be available in the next 5-10 years. This will entail studying not only the capabilities of quantum algorithms, but also the limitations of classical ones. The project will build on Boson Sampling, a well-known proposal by Aaronson and his student Alex Arkhipov that uses non-interacting photons to sample from probability distributions that (under plausible complexity hypotheses) are intractable to sample classically. However, it will go much further to consider the potential for quantum supremacy demonstrations using (for example) noisy bosonic systems, superconducting and ion-trap qubits, and quantum annealing. In support of these goals, Professor Aaronson will also conduct basic research in quantum and classical complexity theory, and build up a quantum information group at the University of Texas at Austin, where he is moving in August 2016.

Oscar Bruno, California Institute of Technology

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Advanced Mathematical Methods in Computational Electromagnetism

Professor Bruno proposes to explore nascent mathematical methodologies that may lead to next-generation accurate and efficient solvers for problems of electromagnetic scattering--with applicability to general engineering structures such as realistic electronic or photonic devices, aircraft, ships, complex electromagnetic or acoustic scenes, etc.--with full engineering detail, and at (possibly) very high frequencies. Elements to be considered as part of this effort include novel windowed Green function methods and recently introduced high-frequency techniques of high-order accuracy as well as spectrally-accurate frequency- and time-domain solvers for general structures.

Marc De Graef, Carnegie Mellon University

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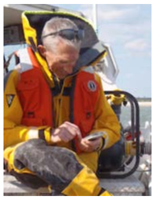
Forward Modeling of Electron Scattering Modalities for Microstructural Quantification in Structural Materials

Professor De Graef will develop a novel open source framework for the modeling of materials characterization modalities that are essential for 3D microstructure quantification. The framework will consist of physics-based forward models for diffraction, image, and spectroscopy modalities in combination with a unified mathematical model for the description of the microstructure. In the long run, this framework will enable researchers in the materials community to both predict the outcome of characterization experiments and to validate microstructural models in a quantitative way.



Steve Elgar, Woods Hole Oceanographic Institution

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What lies beneath? Using remote sensing to determine currents, features, and turbulence below the surface

Dr. Elgar will combine remotely sensed images of the sea surface with in-situ observations of waves, currents, and bathymetry and with numerical model simulations to increase the fundamental understanding of physical processes in the littoral ocean. Anticipated results include an enhanced ability to determine water column flows (and bottom features) from remotely sensed images of the surface, and significantly higher spatial- and temporal-resolution *field-tested* numerical models of littoral processes.

Julia Greer, California Institute of Technology

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Materials by Design: Developing Ultra-lightweight, Damage Tolerant Meta-Materials through Architecture and Nano-structuring

Professor Greer proposes to develop the scientific and engineering foundations for 3-dimensional nano-architected meta-materials that are simultaneously lightweight, damage tolerant, and thermally insulating. A successful execution will shift the paradigm of material creation towards more of a "materials by design" approach and will enable transformative advances in the areas of lightweight damage-tolerant materials, structural mechanics, device integration, photovoltaics, energy storage, and electronic devices. It is the combination of bio-inspired hierarchical design and nanoscale dimensions of the solid that enable de-coupling historically linked properties like strength and density through architectural control. Proposed research enables the fabrication of multiple small-scale samples that combine previously unattainable properties - for example, simultaneous extreme light weight and damage tolerance combined with high strength, exceptional thermal insulation (or conductivity) and energy absorption.

Ali Jadbabaie, University of Pennsylvania

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A New Paradigm for Analysis of Complex, Networked, Social and Engineering Systems

Professor Jadbabaie proposes to develop a rigorous theory of information aggregation, strategic interaction, and systemic risk in complex networks. The proposed research will help us understand how individuals make decisions, how social phenomena spread in networks, and how the structure of underlying social networks can help us determine whether small, local shocks can have large systemic effects. The proposed plan, if successful, will also lead to the development of a new set of tools and methods for analysis of large scale networks that goes beyond graph-heretic approaches and uses tools from algebraic topology to discover structures and patterns in networks for link prediction, develop new sociometric tools for ranking edges, and higher order cliques in terms of their centralities.

Mark Kasevich, Stanford University

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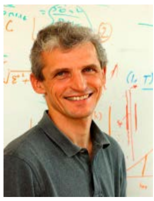
Quantum-Limited Sensing

Professor Kasevich plans to develop and demonstrate new quantum metrological methods which will enable orders-of-magnitude improvement in DoD relevant sensors, including gyroscopes, accelerometers, gravity gradiometers and clocks. These outcomes may represent some of the first demonstrations of the utility of engineered quantum entanglement in practical systems. DoD applications include navigation and time distribution in GPS denied areas, and gravitational tomography.



Wolfgang Ketterle, Massachusetts Institute of Technology

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Quantum Simulators with Ultracold Atoms - mapping out possibilities for new materials

Professor Ketterle will realize and characterize new materials made of ultracold atoms. Assembling materials on a thousand times enlarged scale takes full advantage of the precision and control of atomic physics and is expected to realize an analog quantum computer. The systems of interest are topological, magnetic and superfluid materials. Those materials have special quasiparticles including Majorana fermions, anyons, spinons, and d-wave Cooper pairs. Important results may include the validation of models for high-temperature superconductors, the creation of topological states of matter which have no counterpart in nature, but most likely surprises which are not anticipated.

Daniel Koditschek, University Of Pennsylvania

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Robotics: Toward the New Science of Programmable Work

Professor Koditschek will address the fundamental problem of robotics: the design and deployment of general purpose mechanisms capable of performing user-specified mechanical work within a designated task domain. He seeks to formalize the expression of user goals in terms of target energy landscapes, to determine fundamental physical constraints that govern them, and to develop a family of compositional operators that can allow their flexible recombination through a suitably typed programming language. The project aims to achieve a novel, correct, automated design environment for building robots with unparalleled capabilities and behaviors in consequence of new insights arising from the pursuit of a true discipline based on sound mathematical and physical foundations.

Ying-Cheng Lai, Arizona State University

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Relativistic Quantum Nonlinear Dynamics and Chaos

Professor Lai will launch a comprehensive program into a new field of interdisciplinary research: relativistic quantum nonlinear dynamics and chaos, which recently emerged due to the tremendous interest in Dirac materials. The traditional field of quantum chaos (the study of quantum manifestations of classical chaos) has mostly been for nonrelativistic quantum systems. The new field seeks to discover, understand, and exploit fundamental phenomena arising from the interplay between classical chaos and relativistic quantum mechanics. In terms of basic science, the research will generate a new paradigm at the disciplinary boundaries of nonlinear dynamics, relativistic quantum mechanics, solid-state physics, and applied mathematics. Practically, the research will result in new methodologies of exploiting relativistic quantum nonlinear dynamics and chaos for next generation nanoscale electronics, spintronics, and photonics to benefit future military systems.

Jennifer Lewis, Harvard University

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Programmable Architected Materials

Professor Lewis will create programmable architected materials that heterogeneously integrate functional, structural, and biological building blocks in novel geometric layouts. Her research will lead to foundational advances in materials science, fluid mechanics, and additive manufacturing science. Transformative approaches to the design and fabrication of flexible electronics, lightweight composites, and shape-morphing architectures are expected.

Aude Oliva, Massachusetts Institute of Technology

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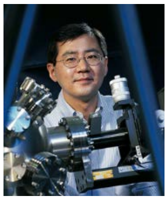
Mapping the Spatio-Temporal Dynamics of Perception in the Human Brain

Dr. Oliva studies the fundamental neural mechanisms of human perception and develops computational models inspired by human brain architecture. Using a state-of-the-art brain mapping approach fusing magnetic resonance imaging, magnetoencephalography, and computational modeling, her team investigates the neural flow of perceived events. Integrating the spatial and temporal dynamics of this processing stream, a decades-long challenge to neuroscience, constitutes a crucial step towards modeling how the human brain creates mental representations and predictions of future events. Dr. Oliva's multi-pronged basic research program is well suited to studying the maintenance of perceptual and cognitive functions in healthy brains, and eventually pinpointing impairments as a precursor to therapeutic interventions.



Hongkun Park, Harvard University

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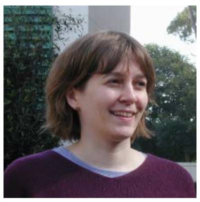
Nanostructured Surfaces for Integrated Optoelectronics, Plasmonics, and Quantum Optics

Professor Park will combine newly developed material and technology platforms – plasmonic metasurfaces, color centers in diamond, and atomically thin transition metal dichalcogenides – to realize photonic and optoelectronic devices that work all the way down to the single-photon level. The proposed research will lay the scientific and technological foundation for solid-state devices for integrated all-optical information processing, and as such, has the potential to revolutionize many research areas and applications, such as data communication and computing, signal processing, and even sensing, and imaging.



Susanne Stemmer, University of California Santa Barbara

stemmer@mrl.ucsb.edu

Engineered 3D Dirac Materials

Professor Stemmer will develop new thin film electronic materials based on the recently discovered class of three-dimensional (3D) Dirac and Weyl semimetals. The project seeks to synthesize 3D Dirac semimetals with high materials perfection and carrier mobilities using molecular beam epitaxy to gain a fundamental understanding of how nontrivial topological electronic states control the properties and phenomena in thin films and heterostructures. Using approaches such as strain, electrostatic confinement, and symmetry engineering, as well as fine-tuning by electric field effect and modulation doping, the project seeks to control and engineer these unique electronic states and identify the opportunities for future electronic device applications.

Alan Willner, University of Southern California

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Multiple Structured Electromagnetic Waves Containing Orbital Angular Momentum for Novel Communications, Imaging, and Directed Energy

Professor Willner proposes to explore various possible effects of multiple electromagnetic waves containing orbital-angular-momentum (OAM). An OAM beam is uniquely structured, such that the spatial phase front "twists" in a helical fashion as it propagates, and different rates of phase change form a set of orthogonal modes. Each different OAM beam has a unique phase front and a central intensity null that are sensitive to disruption by interacting with other beams and with matter. Prof. Willner will study: (i) mechanisms for minimizing and maximizing the linear and nonlinear interactions among beams and with different types of matter; and (ii) dependencies of OAM modal structures under harsh conditions. He will explore the temporal and spatial complex OAM spectra, and he will extract the OAM signatures produced during interaction. The results could impact the capabilities of several disciplines, including: (a) increase in communications capacity and decrease in probability of eavesdropping, (b) improved sensitivity and resolution in imaging, and (c) higher localized intensities when combining beams.

Alán Aspuru-Guzik, Harvard University

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Practical and Scalable Quantum Simulators for Chemistry and Materials

Prof. Aspuru-Guzik will develop a family of quantum algorithms for the simulation of chemistry and materials to create a practical toolset and roadmap for numerically exact simulations. Much of relevance and future success of QIS depends on the availability of quantum algorithms. If successful, this work points the way for how one may exploit quantum platforms as they are currently (small, with no error correction) as well as potential future many qubit, scalable (and with error correction) quantum platforms.

Nader Engheta, University of Pennsylvania

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Materials for Extreme Manipulation of Light, Sound, and Heat

Prof. Engheta proposes to explore new approaches for controlling thermal, acoustic, optical and electromagnetic properties utilizing asymmetric nanostructures. Unique aspects of the work include concepts for heat steering, topologically protected acoustic and photonic surface states, and quantum-cavity optics. His research is expected to lead to new platforms with exciting potentials for optically, acoustically and thermally managed environments.

Robert Ghrist, University of Pennsylvania

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LOCAL-to-GLOBAL: Algebraic Topology for Data, Networks, and Systems

Prof. Ghrist plans to develop novel applications from the mathematical field of *algebraic topology* and *sheaf theory* to applied problems related to the passage from local objects [data, sensing, constraints, intelligence, and relation] to global system-scale information and inference. The technical tools to be used, which have already demonstrated their effectiveness in problems of sensor networks, networked robots, and data aggregation, will be fully translated from ostensibly pure mathematical techniques into a computational data-centric setting, refined according to the constraints of the relevant application domains. This is expected to lead to impacts in a variety of challenge problems and DoD-related areas, including but not limited to sensor fusion, target tracking and disambiguation, pursuit-and-evasion, inference, and radar signal processing.

Jeremy Levy, University of Pittsburgh

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Correlated Nanoelectronics

Prof. Levy proposes a new field of research "Correlated Nanoelectronics". He proposes to develop a microscopic theory to replace the present phenomenological models for the complex-oxide electronics so that new families of quantum-enabled, custom nanoelectronics can be built with novel properties that can, for example, perform quantum simulations. The research is expected to lead to quantum-enabled nanoelectronics, a novel solid-state approach to quantum simulation, and the development of technologically important new materials by design.

National Security Science and Engineering Faculty Fellowship (NSSEFF) - 2015 Fellows

Mikhail Lukin, Harvard University

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Quantum Sensing & Metrology: Novel Methods and Applications

Prof Lukin will make use of recent advances in quantum manipulation of isolated atomic systems and atom-like systems in the solid state to develop a new generation of quantum sensors of increasing sensitivity and sophistication. His project will be complimented by activities in material science, chemistry and nanofabrication. These approaches will open up transformative new research directions in fields ranging from quantum metrology to life and material sciences, which could open the door for unique new capabilities in areas ranging from navigation to medical diagnostics.

Christopher Palmstrøm, University of California, Santa Barbara

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Engineered Heusler Compound Heterostructures and Superlattices

Prof. Palmstrøm proposes to explore the novel physical properties of Heusler compound and heterostructures. Combining Heusler compounds (intermetallic compounds) with different properties into heterostructures and superlattices offers the possibility of engineering novel materials and heterostructures possessing a wide range of magnetic, electronic, and topological properties.

Ivan Schuller, University of California, San Diego

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Bio-Inspired Functional Hybrids: A new paradigm for solid-state devices

Prof. Schuller plans to develop a new paradigm for the synthesis of materials with properties that do not exist in nature. The specific material systems that will be investigated are heterostructured hybrids of strongly correlated oxides, fluorides, and nitrides with metals. Specifically, transition metal oxides that exhibit major structural, electronic, and magnetic transitions will be layered in various configurations with other dissimilar oxides, magnets, and ferroelectrics to produce unique functional properties that can be manipulated at will. These types of materials could potentially become the basis for new high technology systems for electronics, sensors, data manipulation and storage.

National Security Science and Engineering Faculty Fellowship (NSSEFF) - 2014 Fellows

Susan Coppersmith, University of Wisconsin Madison

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Towards Scalable Quantum Computation with Electrically-Gated Silicon Quantum Dot Qubits

Dr. Coppersmith's research currently focuses on the development of quantum information processing devices using electrically-controlled semiconducting quantum dots. This technology has emerged as an attractive candidate for large-scale quantum information processors because of the promise of scalability, manipulability, and integration with existing classical electronics technologies. Her NSSEFF project uses theory, modeling, device design, and experiment to investigate fairly radical device design changes that have the potential to greatly enhance tunability, performance, and scalability of qubits in electrically-gated quantum dots.

Christopher Dwyer, Duke University

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Molecular-scale Energy Transport and Computational Phenomena Enabled by DNA Nanotechnology

Dr. Dwyer will investigate the fundamental properties of self-assembled nanoscale materials that enable the fusion of computation with physical, chemical, and biological systems. Recent advances in the synthesis of deoxyribonucleic acid (DNA) nanostructures have created new opportunities to study and control matter and the flow of information at a molecular level in a variety of physical contexts. Through the precise arrangement of molecular components on DNA scaffolds, single-molecule characterization, and time-correlated single photon detection, it is possible to design and test complex molecular sensing and computational functionality in realistic microenvironments (e.g., in cell culture). Dr. Dwyer's work will build on these successes to create new molecular structures that integrate computational capabilities. He will study the fundamental aspects of phenomena related to computational DNA nanotechnology and how it interacts with and evolves as a function of its environment. DNA self-assembly methods will be used to create and study very high- density circuits built from molecular chromophores to implement resonance energy transfer networks.

Gregory Engel, University of Chicago

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Transcribing Quantum Information Using Quantum Dynamics of Coherent Materials

Dr. Engel will apply two-dimensional (2D) femtosecond laser spectroscopy to complex biomolecules to advance the theory, synthesis, and spectroscopy of coherent phenomena in polymeric materials. He will investigate new polymer materials using a rigid conjugated backbone decorated with chlorophyll molecules. The Soret band of the molecules is in the "blue window" that is accessible for underwater communications. By coupling these molecules coherently, Dr. Engel proposes to create new materials for efficient detection of blue photons, including measurement of orbital angular momentum for quantum information science. He will produce samples for spectroscopic evaluation and materials designed for incorporation into proof-of-principle devices. The goal of this work will be to understand fundamental physical mechanisms of energy transfer so that information contained in the photon mode can be efficiently transferred and processed.

Jian Luo, University of California, San Diego

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Development of Interfacial "Phase" Diagrams for the Materials Genome Initiative: Tailoring the Processing and Properties of Materials for Defense Applications

Dr. Luo's research group is investigating solid interfaces and their roles in controlling the fabrication and properties of a broad range of materials. The first focused area is on studying metallic and ceramic materials for structural applications and uses in extreme environments. An additional focused area is on designing and tailoring materials for energy-related applications, including solid electrolytes, batteries, supercapacitors, photocatalysts and thermoelectric materials. One of his current research thrust is to develop interfacial "phase" diagrams as a materials science tool and a useful component for the Materials Genome Initiative. Dr. Luo's research interests also include field-assisted and flash sintering, nanocrystalline alloys, nanostructured coatings, two-dimensional materials, nanofabrication, materials characterization, optical fibers and sensors.

Chad Mirkin, Northwestern University

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Functional Crystals through Encodable Hard and Soft Matter

Dr. Mirkin's NSSEFF project focuses on developing materials-general methods for the bottom- up synthesis of macroscopic crystals comprised of nanoscale components. The nanoscale components that are used will be a diverse set of building blocks, including proteins and viruses, where oligonucleotides behave as synthetically programmable bonds between nanoparticles. The programmable nature of deoxyribonucleic acid (DNA) will allow for precise control over interparticle distance, crystal symmetry, and crystalline habit independent of nanoparticle composition. By using sequence-specific hybridization events, DNA-modified proteins programmed to exhibit directional bonding interactions with other proteins or nanoparticles will be incorporated into one-, two-, and three-dimensional lattices, thus enabling the ability to bring together combinations of soft (biological nanostructures) components that do not otherwise exist in nature.

Charan Ranganath, University of California, Davis

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Decoding and Enhancing Neural Mechanisms for Episodic Memory

Dr. Ranganath studies the neural mechanisms of memory in healthy individuals and how these processes go awry in patients with memory disorders. His group uses multiple research methods to examine memory, including magnetic resonance imaging, electroencephalography, electrocorticography, eye movement monitoring, and transcranial direct current stimulation. In addition to studying basic mechanisms of memory, Dr. Ranganath's lab is studying how memory changes with healthy aging and how memory is affected by disorders such as epilepsy, stroke, schizophrenia, Alzheimer's disease, and diabetes. Much of the lab's research has focused on identifying how the brain encodes information about the context (when and where an event took place) of an event and, more generally, how the brain represents information about time. His lab is also investigating how motivational and emotional factors influence memory. Finally, his lab is working to understand how neural oscillations—rhythmic changes in activity—support memory processes. With NSSEFF funding, his lab will develop techniques to manipulate neural oscillations to improve memory functioning.

Kaushik Roy, Purdue University

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Ultralow Power Neuromorphic Computing with Spin-Devices

The key insight behind Dr. Roy's proposed research is that emerging nanoscale devices, such as spin-transfer-torque devices, make it possible to realize the neuron, synapse or other biological functionality in a highly energy efficient manner, well beyond the capabilities of complementary metal-oxide semiconductors (CMOSs). This is due to two factors: (1) the inherent match between the characteristics of these devices and the functionality of neuron/synapse/biological functions (leading to a drastic decrease in the number of devices required) and (2) the possibility of ultra-low voltage operation. Inspired by this vision, Dr. Roy will carry out a research program that spans subjects from devices to architectures to investigate spin-based neuromorphic/bio-inspired computing.

Norbert Scherer, University of Chicago

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Harnessing Meso-Scale Electrodynamics and Plasmonics for Enhanced Chemistry, Sensing and Quantum Optics

Dr. Scherer will create a new class of functional materials using light. He proposes to exploit photonic synthesis and self-organization of nanoscale building blocks to construct arrays and three-dimensional (3D) shapes (manifolds) using only electrodynamic interactions and electrostatics. In particular, his proposed research aims to develop new concepts for creating new functional materials using light shaped by optical phase and polarization (in space and time) that tailor mesoscale electrodynamic interactions among the constituent nanoparticle elements. This research is at the nexus of nanoscience and photonics. The mesoscale interactions will be effected using electromagnetic radiation to organize the nanoscale elements. These elements may be metallic, semiconductor, dielectric, plasmonic and/or meta-material in nature, and each can confer a specific property on the collective assembly. These optical matter materials, to be created in solution to allow self-organization and correction of defects, could be fixed in space by photopolymerization and used in novel detector and sensing applications. A long- term goal of this fundamental research is the optimization of detectivity and the converse, to make detection impossible (i.e., cloaking).

Yuri Suzuki, Stanford University

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Engineering Functionality in Emergent Oxide Thin Film Materials Systems

Dr. Suzuki's research is focused on the study of novel ground states and functional properties in condensed matter systems synthesized via atomically precise thin film deposition techniques. These model systems often provide for ground states and functional properties that are not observable in the bulk material. Her recent emphasis has been on highly correlated electronic systems, especially new spintronic materials that address fundamental questions that still exist in magnetism. With NSSEFF funding, she plans to develop a fundamental understanding of the physics of spin current generation and spin transfer without charge flow through model systems based on spinel structure materials. This understanding may provide the foundation for a truly energy-efficient spin current based electronics platform.

Christopher Voigt, Massachusetts Institute of Technology

cavoigt@gmail.com

Synthetic Biology for Advanced Functional Materials

Dr. Voigt's research focuses on synthetic biology and seeks to push genetic engineering to the scale of designing whole genomes. He plans to build and control large multi-gene systems by building regulation to control the timing, spatial organization, and coordination of large multi-gene cellular functions. He will program bacteria to build composite materials using in vivo deoxyribonucleic acid (DNA) nanotechnology and genetic timing circuits; enable spatially organized living materials using a synthetic differentiation system that combines sensing, permanent memory, and a resource allocator; and integrate living cells into a three-dimensional (3D) printer that can control cellular processes with light. Dr. Voigt will develop the platform technologies broadly necessary to generate a leap in our ability to design multi-component (composite) materials.

Meigan Aronson, Stony Brook University

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Designing New Higher Temperature Superconductors

This research project uses theory to guide the synthesis of materials that will be superconducting at high temperatures. Using this new methodology, Professor Aronson will synthesize new families of layered superconductors based on transition metals, using realistic electronic structure calculations to identify the most promising compositions and configurations. This project seeks to determine the maximum superconducting onset temperature possible in lamellar superconductors, and to test whether superconductivity can be deliberately triggered by proximity to electronic delocalization transitions. DOD interest lies in areas such as communications, sensing, power transmission and electric motors.

Alper Atamturk, University of California, Berkeley

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Optimal Design of Resilient Capacitated Networks

Professor Atamturk will do mathematical and algorithmic research on resilient network design with a focus on the tradeoffs between resilience and cost of investment in risk mitigation. The approach builds on his past success in investigating strong polyhedral inequalities that define the convex hull of integer solutions for capacitated network design. The goal is to generalize the polyhedral investigations to networks involving risk for addressing probabilistic failures, uncertain capacities, and adversarial attacks. This would be followed by the development of novel computational methods based on nonlinear integer optimization. Results will be fundamental, not technology or application specific. The research area is relevant to a variety of optimal planning problems and threat assessments. It may help to systematically identify vulnerabilities in networks, efficiently allocate resources to mitigate the vulnerabilities, and quantify tradeoffs between cost of investment in risk mitigation and infrastructure network resilience and between cost and effectiveness of interdiction operations.

Andrew Ellington, University of Texas, Austin

ellingtonlab@gmail.com

Developing Biological Software via Genetically Augmented Proteins

Biological computation is currently limited to the construction of logic gates and accompanying algorithm implementation is via standardized software. Professor Ellington proposes to develop a new genetic material that can pass between cells, carrying executable commands to affect behavior and execute commands in neighboring cells. He will do this by significantly altering a material's genetic code to make it transferrable across cell membranes. (Naturally-occurring DNA can't be transported reliably across cell membranes.) Dr. Ellington proposes to use cells as processors in an amorphous computational algorithm, rather than just as individual logic gates. A second research topic involves the development of advanced RNA logic gates for intracellular commands. This is a challenging task that may provide a capability that is currently unknown. If biological organisms can be made programmable, then new organisms can be engineered for a variety of applications, such as biological threat detectors or bacterial factories that can extract energy from their environment.

Leslie Greengard, New York University

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Novel Methods for Electromagnetic Simulation and Design

Professor Greengard will do research in computational electromagnetics. He has developed a new mathematical representation of electromagnetic fields that seems likely to overcome the difficulties that have plagued standard scattering calculations over the past few decades. The new approach leads to well-conditioned integral equations, no spurious resonances, and no low-frequency breakdown. By using two scalar unknowns on the scattering surface, arbitrary order accuracy should be achievable in a straightforward manner for the first time. Professor Greengard will perform the core mathematical analysis and develop efficient computational approaches by coupling the new representation to fast multipole methods and fast direct solvers; this will permit the accurate simulation of electromagnetic wave interactions in the presence of objects with complicated geometries. The ability to predict the details of electromagnetic scattering by any object in a fast and accurate manner will be transformational; this research is expected to affect antenna design, optical systems design, and materials design.

Lene Vestergaard Hau, Harvard University

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Quantum Control of Light and Matter: from the Macroscopic to the Nanoscale

In 2007, Professor Hau completely stopped a light pulse in one atom cloud and subsequently regenerated it in a different atom cloud 0.2 mm away. In the process light was converted to matter and then, several milliseconds later, back to light. She will now investigate the properties of matter-stored light with the goal of increasing the storage time for quantum optical states to seconds and possibly minutes. (Currently, the storage times for these quantum states are too short for practical quantum networks.) Professor Hau will also create multi- optical-input controlled gates which are the fundamental building blocks in algorithms for quantum information processing. Furthermore, she will explore chip-based nanostructures for atom cooling and trapping, and “optical matter” based self-assembly of photonic crystal cavities for ultra-low-power optical switches. Her proposed work may be transformational in the areas of communication, encryption, and computing.

H. Jeff Kimble, California Institute of Technology

hjkimble@caltech.edu

Quantum Networks with Single Atoms, Photons, and Phonons

Professor Kimble will investigate single atoms strongly coupled to micro- and nano-optical resonators as avenues towards quantum information networks. Currently, laboratory capabilities do not exist for “quantum wiring” atomic, photonic, and phononic systems to achieve scalable quantum networks. He proposes to develop elementary quantum nodes which could someday be scaled and integrated to make quantum information processors. Professor Kimble will explore basic scientific questions related to quantum entanglement in lab experiments with these networks. This work addresses both the fundamental physics of light-matter interaction and provides a step toward practical quantum computing networks. This research may be transformational in the areas of communications, encryption, and computing.

Stephen Leone, University of California, Berkeley

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Attosecond Electron Processes in Materials: Science of Excitons, Plasmons, and Charge Dynamics

Professor Leone will study the processes of electron dynamics in solids using newly developed attosecond laser techniques. (An attosecond is 10-18 seconds, or a billionth of a billionth of a second.) Some of these electron dynamics processes take place in the ~100 attosecond regime. Although gas phase studies in this time regime have been performed, the capability to see electrons moving in solids does not now exist. Until recently, time resolved dynamics has been limited to time scales more characteristic of atomic motions, such as vibrations. These time scales are characteristic of the heavy nuclei in materials and are relatively slow, in the femtosecond (10-15 seconds) regime, about 1000 times slower compared to the motions of electrons. It may now be possible to watch electron processes such as electron density transformations among molecular orbitals, band gap renormalization, and exciton-exciton interactions in semiconductors take place. Professor Leone will study electron dynamics in materials used in solar cells, lasers, plasmonic devices, high speed electronics, etc. If these materials are better understood, there is an increased chance that novel or more efficient devices will be created in the future.

Todd Martinez, Stanford University

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Computational and Theoretical Design of Photo- and Mechano- Responsive Molecular Devices

Professor Martinez will use theory and computation to model chemical dynamics in light- & force-driven molecular devices (such as switchable photoactive proteins and mechanically activated polymers). He will use quantum mechanical calculations instead of conventional force field modeling to investigate the mechanism of fluorescence switching and the role of chemical attachment in force sensitive reactivity. The molecular systems chosen for study are all amenable to experimental synthesis and characterization, so predictions arising from this work will be testable. Professor Martinez will develop computational algorithms using stream processors that are available in consumer graphics cards. With new algorithms on these new architectures, computational throughput is anticipated to increase a hundred-fold or even more. This enhanced speed will enable molecular design which has been stymied until now because of its prohibitive computational cost. The methods and strategies being developed in this project could enable the design of new materials and devices such as detection systems for pathogens or explosives, self-healing materials, and colorimetric materials for propellants.

Monica Olvera de la Cruz, Northwestern University

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Paradigms for Emergence of Shape and Function in Biomolecular Electrolytes for the Design of Biomimetic Materials

Professor Olvera de la Cruz will investigate how shapes & patterns emerge in biomolecular assemblies, from nucleic acid organization & membrane functions to cell compartmentalization. Living matter is very inhomogeneous at the nanoscale in both composition and electrical charge. Professor Olvera de la Cruz wants to determine how these inhomogeneities generate functions such as replication, segregation into components, and transport. She will develop mathematical models based on information collected in vivo and in situ in order to understand structure-function relationships. Understanding the interaction of charged particles in aqueous solutions will lead to methods for design of functional self- assembled nanostructures.

Leonid Ryzhik, Stanford University

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Mathematical Modeling in Random Media: from Homogenization to Stochasticity

Professor Ryzhik will develop mathematical models to predict the behavior of waves and particles in random media. Numerical simulations and real data show that wave energy in random media has significant fluctuations even close to the regimes where current theories predict energy self-averaging. The nature of these fluctuations needs to be understood in order to apply predictive capabilities to imaging and other problems of practical interest. The current state of the art uses separation of scales to simplify the models, which results in predictions that are self-averaging and deterministic. Professor Ryzhik will develop the theory to go beyond that assumption. This is a critical topic for imaging through random media, such as in radar and infrared imaging applications.

Guillermo Sapiro, Duke University

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Information Acquisition, Analysis, and Integration

Professor Sapiro's research is in the area of image acquisition and analysis. He will develop mathematical and computational frameworks to efficiently represent data based on sparse coding of images over learned dictionaries. Professor Sapiro will investigate the minimum way that visual data can be represented using a learned dictionary. His work bears some similarities to the way human brains work (basic dictionaries to put objects in contexts so what one doesn't know about the other objects in a scene can be inferred). This framework will be optimized over the entire image processing pipeline, combining acquisition, analysis, and integration. Professor Sapiro's research is expected to enable advances in the areas of image acquisition and analysis for intelligence, surveillance, and reconnaissance applications, as well as in the areas of robotics and sensing.

Graham Candler, University of Minnesota

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Multi-Physics Simulations of Hypersonic Flows

The US Department of Defense is developing new systems to support prompt global strike, missile defense, and responsive space access. These vehicles will fly through the atmosphere at high Mach number, where the flow field is dominated by high temperatures, strong shock waves, finite-rate chemical reactions, and other non-ideal effects. Prof. Graham Candler is developing first-principles physical models and advanced computational methods for the numerical simulation of these hypersonic flows. His work will advance the accuracy of hypersonic flow simulations, answer unsolved puzzles in hypersonic flow physics, and enable optimized designs of future high-speed systems.

Steve Elgar, Woods Hole Oceanographic Institution

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Manipulating Nearshore Morphology to Determine the Coupling and Feedback Between Waves, Currents, and Bathymetric Change

Operations in shallow water, including surfzones, estuaries, tidal flats, and rivers require accurate maps of the seafloor. However, the seafloor in these dynamic areas can change rapidly. Storm-induced waves can move sandbars hundreds of meters in a few hours. Craters created during mine- and obstacle-clearing operations can generate strong currents, and can cause rapid and significant sediment transport, burying objects in its path, while exposing those left in its wake. River channels in estuaries and on tidal flats change shape and location in response to tides and floods, making routes for safe ingress and egress difficult to determine, and resulting in grounded vessels and vehicles. Although remote sensing allows these areas to be mapped in some detail, computer models are required to update the maps as the seafloor changes in response to storms and floods. Dr. Elgar will perturb the seafloor in shallow water and monitor the nonlinear, coupled response of the seafloor, waves, and currents. This technique allows detailed investigation of the underlying physics and will help produce better models of the storm- and flood-induce evolution of the shallow-water seafloor, allowing maps to be kept accurate.

Sharon Glotzer, University of Michigan

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Smart, Autonomous, Adaptive Phenomena in Self-Organizing, Reconfigurable Materials

Next generation materials for defense applications will be distinguished by their ability to adapt in novel ways both on demand and to environmental cues in order to perform important functions. Dr. Glotzer will use computer modeling and simulation to discover the fundamental principles of how nanoscale systems of building blocks self-assemble, and to design materials that can be dynamically reconfigured in response to stimuli, controlled tuning, or changing of properties based on environmental cues. Long term applications may include wearable fabrics that feel cooler or warmer depending on temperature; paints and coatings that toggle between reflective and non-reflective states, synthetic colloidal clotting agents for on-the-spot battlefield treatment, or materials that can control their motility on command.

Naomi Halas, Rice University

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3D Nanophotonics: Bending Light in New Directions

Dr. Halas will use her understanding of light-matter interactions at the nanoscale and her expertise in nanomaterials fabrication to design and fabricate infrared and optical materials that manipulate light in new ways. She will design new optically active nanostructures based on systems of 3D reduced symmetry (metallic hemispheres with dielectric cores), characterize and understand their physical properties, and fabricate and pattern them into new optically active materials and devices. This effort will result in new light- harvesting strategies for solar-based devices, engineered nonlinear materials with high conversion efficiency, and new active materials whose optical properties can be controlled and manipulated at will (e.g. metafluids for concealment applications).

Mark Kasevich, Stanford University

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Atomic de Broglie Wave Navigation Sensors

In recent years, quantum-level control of atoms using light has enabled demonstration of precision atom-based accelerometers and gyroscopes. The proposed work seeks to advance the state-of-knowledge for this class of sensors by investigating the science of atomic sources, atom optics, and atom detection methods. Dr. Kasevich will also develop and demonstrate techniques which will lead to substantially improved sensor performance. These improved sensors will be used in laboratory tests of Einstein's Theory of General Relativity. Long-term defense applications include very high performance navigation systems and gravitational sensors.

Charles Lieber, Harvard University

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One-Dimensional Nanostructures as Building Blocks for Functional Electronic and Bioelectronic Materials

Dr. Lieber will develop new nanoscale materials as building blocks for functional electronic and bioelectronic materials. He will focus on the scientific understanding and development of photovoltaic devices based on inorganic nanowires. The research will pioneer new classes of functional nanostructures for electrical power generation, ultrasensitive electronic nanobiosensors on biocompatible chips, and novel combinations of nanoscale power sources and sensors on single chips.

Christine Ortiz, Massachusetts Institute of Technology

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Natural Armor: An Untapped Encyclopedia of Engineering Designs for Protective Defense Applications

An understanding of the protective mechanisms in biological systems has enormous potential for providing a tactical advantage to the U.S. Military. The personal armor of the future must become more multifunctional and effective against numerous threats such as bullets, shrapnel, fire, blast overpressure and explosive effects, while still allowing necessary mobility, thermal regulation, and proper hygiene. We can learn much from biological organisms that have evolved over millions of years. Their protective mechanisms provide environmentally-friendly engineering designs for protection against specific predatory and environmental threats, including kinetic impacts, dynamic penetration, blast, heat and thermal fluctuations, fire, and biochemical toxins. Dr. Ortiz will create a comprehensive knowledge base of natural armor design principles linked to their corresponding threats. Transfer of this knowledge base to DOD armor specialists is planned to implement the new scientific concepts discovered into prototype human, vehicle, and structural armor kits (intermediate term) and the development of a new, improved biologically-inspired human armor suit and armor structures (long-term).

John Rogers, University of Illinois, Urbana-Champaign

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Materials and Mechanics for Stretchable Electronics/ Optoelectronics

Electronic circuits that involve transistors and other components on thin plastic sheets or rubber slabs offer mechanical properties (e.g. bendability, stretchability) and other features (e.g. rugged, lightweight construction) that cannot be easily achieved with conventional wafer-based technologies. Device examples include personal or structural health monitors and electronic eye imagers, in which electronics must conform to complex curvilinear shapes or flex/stretch during use. Dr. Rogers is developing single crystalline inorganic nanomaterials in 'wavy' buckled configurations on elastomeric supports for this type of technology. He will explore the fundamental materials and physics aspects of these approaches, and engineering features of their use in individual transistors, photodiodes and integrated circuits. The foundational efforts will be guided by two testbed applications: one in conformal brain monitoring devices and another in surveillance cameras with layouts inspired by the human eye.

Scott Strobel, Yale University

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Exploitation of Diesel Producing Fungi as a Renewable Source of Fuel

Our project concerns an emerging biotechnology for the production of hydrocarbons from cellulose-based waste feedstock with a low-carbon footprint. *Ascocoryne sarcoides* (NRRL 50072) was isolated from northern Patagonia as an endophyte of *Eucryphia cordifolia*. It produces a broad spectrum of medium chain-length hydrocarbons and related alcohols, esters and ketones. This organism has the potential to produce desirable biofuels via a fermentation process that is nearly carbon neutral. Strobel will investigate the molecular mechanisms of medium chain hydrocarbon production, determine if these compounds are a suitable substitute for gasoline or kerosene, and explore biosynthetic methods for hydrocarbon production.

Andrew Weiner, Purdue University

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Novel Ultrabroadband Photonic and Radio-Frequency Systems

Radio-frequency (RF) technology is ubiquitous in systems such as radar, sensing, wireless communications, and electronic warfare (EW) that are vital to national security. Conventional RF systems are usually designed to operate at relatively low instantaneous bandwidth with signals possessing a well defined center frequency. On the other hand, optical systems can be extremely broadband, generating pulses with durations down to femtoseconds and with terahertz instantaneous bandwidths. Dr. Weiner plans to generate and process extremely wide RF bandwidths in the optical domain. He proposes to do research into enabling technologies that will combine optical and RF waveform generation, timing, and control. He will demonstrate RF-photonics hybrid subsystems for RF transmitters and receivers with wide bandwidths. Such systems may enable new capabilities in areas such as radar, high power EW pulse generators, RF spectrum monitoring, covert wireless, and signature recognition of remote devices.

Connie Chang-Hasnain, University of California, Berkeley

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Nanostructured Materials for Low Power, Low Weight, High Performance Electronic and Optoelectronic Devices

Nanostructured semiconductors are an emerging, new class of materials which are poised to dramatically advance performances and extend capabilities of devices for many applications. With two or three dimensions on the nanometer scale, nanostructured materials can be designed to exhibit properties that are significantly different from their bulk counterparts due to quantum confinement of electrons. The field has made strides in the realization of nanostructures in various materials. However, little progress has been made in the controllability of physical parameters of nanostructures and the resulting properties. Most importantly, the nanomaterials cannot be readily made into electronic and optoelectronic devices. Dr. Chang-Hasnain will develop a comprehensive program to synthesize nano-materials with controllable properties by means of metal-organic chemical vapor deposition. She will study growth kinetics through both simulations and experiments. She will also investigate the fabrication of new solar cells, bio/chemical sensors and lasers, leveraging the novel properties arisen from nanostructured materials, to result in an enhanced performance with orders of magnitude reduction in power consumption, size and weight.

Diana Huffaker, University of California, Los Angeles

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Exploring Dissimilar and NanoMaterials Integration as a Platform for New MWIR Device Functionality

The MWIR spectral region is of interest to the military due to transparent atmospheric windows with important blackbody emission signatures. Lattice mismatch in sensing devices for this region causes strain that degrades performance, and lack of ideal substrate technology limits high volume, large size device technology platforms. Dr. Huffaker will explore the basic science underlying an epitaxial growth technique (called interfacial misfit dislocation or IMF) for stress relief of dissimilar materials with mismatched lattice spacing. In the IMF technique, the lattice constants are manipulated using epitaxial growth of different semiconductor material layers with an interfacial misfit atomic layer between the 2 materials. Complete strain relaxation can result from a periodic array of skipped inter-atomic bonds at an interface of dissimilar materials. She plans to combine dissimilar material integration and nanomaterials synthesis to improve quality of a collection of MWIR optoelectronic devices. This work may revolutionize the ability to mix materials with much larger lattice mismatch than previously thought possible, leading to better device quality and higher yield, and therefore lower costs.

Stephen Mayo, California Institute of Technology

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Engineering Proteins for Viral Applications

Dr. Mayo will investigate engineering proteins for anti-viral applications. The main focus of this effort is to develop an efficient algorithm that can search the sequence space associated with a number of structural states and return a structure that is capable of binding both states (antigen/antibody complexes). Success will allow protein-based medical countermeasures to select infectious agents of interest to DoD.

Chad Mirkin, Northwestern University

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Functional 1-D Structures Based Upon On-Wire Lithography (OWL)

Dr. Mirkin will research functional one-dimensional nano structures based on on-wire lithography (OWL). OWL is a template-based electrochemical synthesis process that allows one to precisely control the diameter, length, and chemical composition of nanowires with sub-5nm control over architectural features (segment length, gap size). Some specific objectives include determination of the ultimate resolution limits, nanowire shape possibilities and materials compatibility, the development of nanodisk arrays and electrical nanotraps for point-of-use chem/bio detection, and the development of OWL-based molecular transport junctions for high throughput study of molecular electronics. Proof-of-concept studies have shown that OWL can be used to make several interesting architectures for spectroscopic enhancement, biological labeling, nanomechanics, and nanoelectronics.

Margaret Murnane, University of Colorado, Boulder

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Development of High Power Ultrafast Lasers and Applications in Hyperspectral Imaging and Nanotechnology

Dr. Murnane will advance the science necessary to develop compact high average power MWIR ultrafast lasers and investigate the extreme nonlinear optical techniques required to generate coherent beams of hard x-rays for tabletop x-ray sources. High power MWIR ultrafast lasers do not yet exist, but are required to produce coherent hard x-rays in a compact configuration. The hard x-rays are to be generated using an extreme nonlinear optical technique that relies on a new ability to manipulate electrons on attosec timescales and Angstrom spatial scales. This work is expected to ultimately generate light sources for new capabilities and expanded spectral ranges. Wavelengths and bandwidths that are not currently covered by commercial sources will be enabled.

Carey Priebe, Johns Hopkins University

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Fusion and Inference from Multiple and Massive Disparate Data Sources

Dr. Priebe will develop mathematical techniques to combine massive amounts of data from disparate sources and derive meaningful conclusions based on this information. A general concept of an approach to iterated fusion of disparate data sets using iterated subsetting of joint subspaces of data sets will be developed. He will use a method called "iterative denoising" to partition high-dimensional mixed-type data to identify the most informative clusters. Given such a partitioning, the method will explore the implication of this classification within a single data type. Improvements made within that data type yield information that informs a new partitioning of the full mixed-type data set. This is a mathematics research area in pattern recognition.

Barbara Shinn-Cunningham, Boston University

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Managing Acoustic Communications in High-Stress Settings

Dr. Shinn-Cunningham will research managing acoustic communications in high-stress settings. She will develop an understanding of how attention influences auditory perception, and will focus on cognitive enhancement, i.e. how to convey maximum information in a high stress setting without overloading the human subject. Acoustic communications are not optimized well in many displays because past work has focused on how to present visual information. Dr. Shinn-Cunningham will combine behavioral studies with non-invasive neuro-imaging studies to determine how to design effective auditory displays. This work is important to noisy command centers and other military environments.

Susan Trolier-McKinstry, Pennsylvania State University

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High Strain Actuators for Miniaturized Actuators and Self-Powered Sensors

Dr. Trolier-McKinstry will explore high strain actuators for miniaturized actuators and self-powered sensors. She will investigate the use of texture, base composition, and compositional heterogeneity in developing a new family of piezoelectric films. She is developing local measurements of the piezoelectric response, in order to develop an understanding of how the piezoelectric nonlinearities evolve. She will also investigate the chemistry involved in direct patterning of these complex oxide materials without degrading stoichiometry or crystallinity. Finally, she will investigate low temperature processing routes for these high strain piezoelectrics to enable integration with CMOS and polymers. The higher piezoelectric response available in ferroelectric films enables lower voltage operation of actuators, as well as high sensitivity sensors.