Interdisciplinary materials research and education addressing fundamental problems in science and engineering that are important to society

The National Science Foundation Materials Research Science & Engineering Centers Program was established in 1994.

Materials Research Science and Engineering Centers are supported by the National Science Foundation (NSF) to undertake materials research of scope and complexity that would not be feasible under traditional funding of individual research projects.

THESE CENTERS:

- require outstanding research quality, intellectual breadth, interdisciplinarity, flexibility in responding to new research opportunities, support for research infrastructure, and foster the integration of research and education in the materials field;
- address fundamental, complex problems of intellectual and societal importance,
- contribute to national priorities by fostering active collaboration between academia and other sectors, and
- constitute a national network of university-based Centers in materials research.

Center Characteristics

The MRSECs constitute a spectrum of coordinated Centers of differing scientific breadth and administrative complexity that may address any area (or several areas) of materials research.

- Each MRSEC encompasses two or more **Interdisciplinary Research Groups (IRGs)**.
- Each IRG involves a diverse group of faculty members, associated researchers and students addressing a major topic in materials research.
- In each IRG, sustained support for interactive effort by several participants with complementary backgrounds, skills, and knowledge is critical to progress.

Each MRSEC also incorporates most or all of the following activities to an extent commensurate with the size of the Center:

- Programs to stimulate interdisciplinary education, including research experiences for undergraduates accessible to students from other institutions, and the development of human resources (including support for under-represented groups).
- Active cooperation with industry, other institutions, and other sectors, including international collaborations, to stimulate and facilitate knowledge transfer among the participants and strengthen the links between university-based research and its application.
- Support for shared experimental facilities, properly equipped and maintained, and accessible to users from the Center and elsewhere.

Each MRSEC has the responsibility to manage and evaluate its own operation with respect to program administration, planning, content and direction.

Recently, a Materials Research Facilities Network (MRFN) was established. The MRFN is a nationwide partnership of the Shared Experimental Facilities (SEFs) supported by the NSF MRSECs. The MRFN is designed and operated to provide support to researchers and experimental facilities engaged in the broad area of Materials Research in academic, government and industrial laboratories around the world.

NSF support is intended to promote optimal use of university resources and capabilities, and to provide maximum flexibility in setting research directions, developing cooperative activities, and responding quickly and effectively to new opportunities. To this end, NSF encourages MRSECs to include support for junior faculty, high-risk projects, and emerging areas of interdisciplinary materials research.

MRSEC Review and Awards

MRSECs are reviewed initially as pre-proposals, then by invitation as full proposals. See the latest MRSEC Proposal Solicitation (NSF 13-556) for details. NSF does not normally support more than one MRSEC based at any one institution. Awards range in size from about $1.6 million to $3.6 million per year and are made for an initial period of up to six years. Renewed NSF support will be awarded only on the basis of comprehensive, competitive merit review.

For more information see:

http://www.mrsec.org
http://www.mrfn.org
http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5295

2015 Active NSF Materials Research Science and Engineering Centers

Brandeis University – Bioinspired Soft Materials
http://www.brandeis.edu/mrsec/index.html**, Director: Seth Fraden**

The Brandeis MRSEC seeks to create new materials that are constructed from only a few simplified components, yet capture the remarkable functionalities found in living organisms. In addition to opening new directions in materials science research, these efforts will elucidate the minimal requirements for the emergence of biological function. This challenging endeavor draws on expertise in diverse and complementary experimental and theoretical techniques that span the physical and life sciences. Brandeis offers an ideal environment for such an interdisciplinary undertaking. Its small size engenders a highly collaborative environment. Its innovative graduate program trains students who work and thrive at the interface of physical and life sciences. The Brandeis life science faculty have pioneered biochemical studies of molecular motors and cytoskeletal machinery, its chemists have synthesized biocompatible self-assembling filaments, and its physicists have made important contributions toward understanding soft materials such as liquid crystals, gels and colloids. Starting from this background of excellence in molecular biology and soft materials science, and with support of the Brandeis MRSEC, this group of individuals will collaborate to combine elemental building blocks, such as motor proteins, DNA origami and filamentous virus, to understand the emergence of biomimetic functionalities that are highly sought-after in materials science and to synergistically engineer life-like materials. The MRSEC supports an innovative program targeted to inner-city minority science undergraduates at Brandeis.

The goal of **IRG1, Membrane based Materials,** is to uncover the design principles that cells use to shape and reconfigure membranes, and to apply these principles in order to engineer heterogeneous and reconfigurable membrane materials. To accomplish this they will exploit the analogy between nanometer-sized lipid bilayers and micron-sized colloidal monolayers assembled from filamentous viruses or DNA origami rods.

The goal of **IRG2, Biological Active Materials,** is to create active analogs of quintessential soft matter systems including gels, liquids crystals, emulsions and vesicles using elemental force generators, such as motor proteins and monomer treadmilling. They will experimentally and theoretically characterize the emergent properties of such materials, including their ability to convert chemical energy into mechanical work, perform locomotion, and undergo dynamical reconfiguration.

University of California at Santa Barbara – Materials Research Laboratory (MRL),
http://www.mrl.ucsb.edu/**, Co-Directors: Craig Hawker and Ram Seshadri**

Recognized as one of the leading materials research facilities in the world, the MRL serves as an innovation engine for discoveries in new materials. Driven by stakeholders, the MRL is home to a scientific and engineering community that creates new collective knowledge and fosters the next generation of scientific leaders. By enabling modern technological advances, the high-impact research conducted at the MRL and its affiliated centers has enormous societal impact, and is shaping the future of technology, the environment, and medicine. The MRL investigates a wide range of materials including functional hard and soft matter of relevance to biology, the chemical industry, the electronics industry, and energy efficiency. MRL scientists and education staff are dedicated to improving access to science for diverse groups and to building a competent and inclusive work force of scientists and engineers. Our education programs provide undergraduate research opportunities, graduate student and post-doctoral training, outreach to K-12 students and teachers, and community outreach. Significant effort is also devoted to successful International Outreach and Entrepreneurial programs including active collaborations with a variety of small to large companies. These activities, together with a major focus on world-class characterization facilities and networks thereof, have direct benefit to the campus and national materials research community. The MRSEC is composed by the following three interdisciplinary research groups:

IRG 1, Bio-Inspired Wet Adhesion: A fundamental challenge in materials science is engineering durable adhesive bonds in a wet environment; something most synthetic systems have so far been unable to achieve. The long-term goal of this IRG is to understand the fundamental design principles involved in bio-adhesion, achieve translation to synthetic systems, and pioneer a systems approach to wet bonding that spans nano- to macroscale dimensions.

IRG 2, Correlated Electronics: This IRG is developing of the scientific foundation of new technologies based on the unique transport properties of complex oxide heterostructures prepared with unprecedented perfection and purity.

IRG 3, Robust Biphasic Materials: This IRG is tackling the grand challenge of controlling bulk inorganic materials with built-in nanostructures, to develop composite architectures that enable new domains of electrical, thermoelectrical, and magnetic material properties to be accessed. Major objectives include elucidating a fundamental understanding of the novel properties arising from the presence and interaction of two phases; developing synthetic strategies that allow these materials to be fabricated in sufficient quantities, greatly expanding their availability and interest; and designing the structural parameters required for robust operation in harsh, engineering environments.

University of Chicago - Materials Research Center, http://mrsec.uchicago.edu/, Director: Ka Yee Lee

The Chicago MRSEC has established a highly successful, multidisciplinary approach to issues of technological importance at the forefront of materials research. The overarching goal, common to all of the Interdisciplinary Research Groups (IRGs), is to produce the design principles for the next generation of materials that will enable the creation of materials with novel properties and functions of technological importance. The proposed research attacks problems beyond the reach of a single investigator or even a single discipline, and necessitates the assembly of researchers with complementary expertise as well as the coupling of experiments, theory and simulation. The MRSEC draws talents from twelve academic units and from Argonne National Laboratory and our PREM partner at the City College of New York. While each interdisciplinary research group (IRG) focuses on a specific topic, the IRGs are linked scientifically and constitute a synergistic and powerful whole, through carefully conceived, center-wide programs. Not only are efforts collaborative within an IRG, but results from each IRG also inform the work in the others. The research activities of our MRSEC are organized into three IRGs:

IRG 1, Dynamics at Soft Interfaces*,* focuses on both scientific challenges and exciting technological opportunities that arise from controlling and manipulating how much or how fast a soft interface forms or deforms. The systems under study range from nanoscale colloids to macroscopic field-activated suspensions. The research will establish the link between the interface dynamics and the properties of the material as a whole, and will open up opportunities for designing specific material responses that will provide a pathway towards innovative applications.

IRG 2, Spatiotemporal Control of Active Materials, represents an ambitious effort to understand, design, and synthesize materials containing distributed molecular elements that convert chemical energy into mechanical work. This IRG aspires to achieve control of active materials and ultimately to create novel molecular assemblies for robust tunable shape change.

IRG 3, Engineering Quantum Materials and Interactions, seeks to elucidate, manipulate and exploit quantum coherence in materials, from microscopic quantum centers to macroscopically entangled materials. Potential technological impacts include sensors using quantum centers, enhanced energy transport efficiency via engineering coherent couplings in meta-materials from individually coherent components.

University of Colorado - Soft Materials Research Center
http://lcmrc.colorado.edu/, Director: Noel Clark

The research of the SMRC is organized into two Interdisciplinary Research Groups, the LIQUID CRYSTAL FRONTIERS (LCF) IRG, and the CLICK NUCLEIC ACIDS (CNA) IRG. This research and the SMRC outreach activities pursue three main goals: field-defining materials science and engineering; enhancement of science literacy and achievement; and creation & development of advanced soft materials applications and technologies. Nearly 20 years of NSF MRSEC support has catalyzed a transformative growth and diversification in materials research at UCB, a context that provides the foundation for these activities. The SMRC focuses on the discovery of new materials phenomena and new materials paradigms. Each IRG is a highly collaborative team that melds materials design, synthesis, and physical study into a web that drives and facilitates the evolution of new materials and materials concepts, as follows:

Liquid Crystal Frontiers, IRG 1, is one of the principal centers of liquid crystal (LC) study and expertise in the world, with research ranging from basic LC and soft materials science to the development of enhanced capabilities for photonic, chemical, and biotech applications of soft materials. Of particular interest are: new LC structural themes that exploit the interplay of chirality and polarity, such as the heliconical nematic and helical nanofilament phases; novel LC phases of colloidal plates and rods including ferromagnetic nematics; LC interaction with topologically complex colloids; nanoporous LC polymers for electrolytes and organic photovoltaics; active interfacial LCs for biodetection; chromonic LC mixtures; and hierarchical self-assembly of nanoDNA.

Click Nucleic Acids, IRG 2, will pursue a broad exploration of the sequence directed self-assembly (SDSA) of functional materials based on DNA analogs made using click chemistry. Recent years have seen breathtaking advances in nanoscale science of SDSA using DNA. The resulting proof-of- concept achievements promise new DNA-based technologies but realizing this potential in the materials realm will require enhanced scalability, dramatically lower cost, and a greatly expanded molecular structural palette than is available with DNA. CNAs are DNA analogs in which the monomer backbone/base units are joined using photo-initiated thiolene click ligation, a family of elegant chemistries known for robust, orthogonal reactions to completion and stoichiometric reactant use, enabling CNA oligomers and polymers to be made in volume reactors with monomer chain and base structures that can be widely tuned. An exciting palette of CNA applications in nano- and bio-sciences is proposed.

Colorado School of Mines – Renewable Energy Materials
http://remrsec.mines.edu/REMRSEC/Home.html**, Director: Craig Taylor**

This MRSEC focuses on transformative materials research and educational directions that would significantly impact emerging renewable energy technologies. A strategic partnership with scientists and engineers at the National Renewable Energy Laboratory allows sharing of students, research associates, equipment and facilities between the two organizations. In addition, the Center collaborates with companies that are actively involved in alternative energies.

IRG 1, Materials for Next Generation Photovoltaics, aims to producing transformative changes in photovoltaic technology either through significant improvements in materials properties or the development of concepts for more efficient carrier generation and collection.

IRG 2, Advanced Membranes for Energy Applications, seeks to design novel transport membranes with highly optimized properties for electrochemical energy storage or conversion systems.

Columbia University – Columbia Center for Precision Assembly of Superstratic and Superatomic Solids
http://nano.columbia.edu/mrsec, **Director: James Hone**

This MRSEC, led by Columbia University in partnership with City College of New York, Harvard University, Barnard College, and the University of the Virgin Islands, encompasses two IRGs that build higher dimensional materials from lower dimensional structures with unprecedented levels of control. Both IRGs are built around techniques pioneered by the team, and bring together researchers with diverse capabilities, strong accomplishments, and an exemplary record of collaboration. The unified center will enable formation of the interdisciplinary teams required to undertake the proposed research, support of shared experimental tools, implementation of a multi-faceted program of education and human resources development, and focused efforts to improve diversity. The MRSEC leverages the proximity of Columbia, CCNY, and Barnard for intercampus cooperation, and nearby K-12 schools for educational activities. Brookhaven National Laboratory, IBM, DuPont, and other partners provide research partnerships and educational opportunities. The supported IRGs are:

IRG 1, Heterostructures of van der Waals Materials, combines two-dimensional van der Waals materials into pristine layered heterostructures. Under an existing MIRT program, this team has demonstrated successful collaboration to develop proof-of-concept heterostructures with unprecedented size, perfection, and complexity, giving us the ideal building blocks for the current effort. This IRG focuses on three research thrusts: (1) Expanding the class of available materials, particularly using synthetic methods that produce large-area films; (2) Measuring and controlling the properties of atomically thin vdW materials in a protected, ultralow-disorder environment; and (3) Creating new interfaces that exhibit emergent electronic phenomena.

IRG 2, Creating Multi-functional Materials From Superatoms, assembles new classes of functional materials using precisely defined superatom building blocks coupled together with new forms of inter-superatom bonding. This approach will combine encoding of desirable physical properties within the building blocks with exquisite control of inter-superatom interaction, to create materials with tunable properties and multiple functionalities. This IRG will develop and expand the superatom concept into a large "periodic table" to enable designer materials with unprecedented levels of complexity and functionality. It will initially focus on three materials areas: (1) Materials with independent control over magnetism and conductivity. (2) Materials with independent control over thermal and electrical transport properties. (3) Superatom assemblies that can have electronic phase transitions that may be induced by optical, mechanical, thermal, and other stimuli.

Cornell University – Cornell Center for Materials Research
http://www.ccmr.cornell.edu/ **Director: Melissa A. Hines**

The focus of the Cornell Center for Materials Research (CCMR) is Mastery of Materials at the Nanoscale. The central mission of the Center is to explore and advance the design, control, and fundamental understanding of materials through collaborative experimental and theoretical studies. The Center focuses on forefront problems that require the combined expertise of interdisciplinary teams of Cornell researchers and external collaborators. The CCMR research program is organized into three IRGs (interdisciplinary research groups) and a number of Seeds (smaller groups exploring new topics). Three other activities complete the CCMR's mission: educational outreach to K-12 teachers, students, and undergraduates; industrial outreach and knowledge transfer; and the operation of Shared Facilities that serve the broader materials research community, both on- and off-campus, as well as the IRG and Seed research programs. The goal of the research program is to explore fundamental challenges in interdisciplinary materials research that both impede technological progress and have a scope and complexity that require the sustained contribution of researchers from multiple disciplines.

The theme of **IRG 1, Controlling Complex Electronic Materials,** is to understand and control complex electronic materials in which quantum many-body interactions can produce spectacular electronic and magnetic properties, such as colossal magneto-resistance, giant thermoelectric power, and high-temperature superconductivity. Starting from materials that are reasonably well described by current theory, the group is systematically perturbing the electronic structure of the targeted materials through experimentally-accessible changes in electron overlap or carrier density, using observed changes in materials properties to drive advances in electronic structure theory.

The goal of **IRG 2**, **Mechanisms, Materials, and Devices for Spin Manipulation,** is to understand and apply new mechanisms to manipulate electron spins in ferromagnetic and non-ferromagnetic materials. Advances in spin control may enable a variety of applications, including nonvolatile magnetic random access memories capable of being scaled to very high densities and spin-torque "nano-oscillators" in which magnetic precession driven by spin torque from a DC current generates a frequency-tunable microwave source.

IRG 3, **Atomic Membranes,** is exploring an exciting new class of two-dimensional, free-standing materials only one atom thick yet mechanically robust, chemically stable, and virtually impermeable. Applications for these membranes loom in almost every technological sector from electronics to chemical passivation to imaging if major materials challenges can be addressed.

Duke University - **Triangle Center for Excellence for Materials Research and Innovation: Programmable Assembly of Soft Matter,**
http://mrsec.duke.edu, **Director: Gabriel Lopez**

The goal of this MRSEC is to extend the frontiers of materials research by exploring, harnessing and exploiting the dynamic properties and processes related to multicomponent particulate and macromolecular assemblies. Our research effort encompasses materials theory, synthesis, processing and applications. Areas of emphasis include multicomponent colloidal assembly through comprehensive interaction design and genetically encoded polymers for programmable hierarchical self-assembly. Their efforts include: synthesizing new colloidal and biopolymer components for programmed assembly; studying and predicting assembly of these components in response to external stimuli (e.g., electric, magnetic and thermal fields); creating sophisticated new materials systems with useful functionality; translating these materials and applications to industry; and educating and mentoring a new generation of researchers in an emerging area of materials science. The MRSEC supports two IRGs:

IRG 1, Multicomponent Colloidal Assembly by Comprehensive Interaction Design, has the goal to develop a fundamental understanding of self-assembly of bulk materials from multi-component colloidal suspensions. Research outcomes will make possible the fabrication of new classes of soft matter and composites with precisely controlled microstructures and unique properties.

IRG 2, Genetically Encoded Polymer Syntax for Programmable Self-Assembly, has the overall goal of to learn, through experiment, theory, and simulation, the syntactical rules for the design of "syntactomers" whose phase behaviors facilitate programming of their self-assembly into supramolecular nano- to mesoscale structures. Syntactomers developed in this IRG will offer new opportunities for the tunable control of macromolecule sequence, structure, self-assembly, and function.

Georgia Institute of Technology – The Georgia Tech Laboratory for New Electronic Materials
http://mrsec.gatech.edu/, Director: Dennis Hess

This Center (the only 1 IRG MRSEC remaining) addresses the need for new electronic materials and associated processes for applications in microelectronics, optics and sensors. The single Interdisciplinary Research Group on Graphene Science and Technology investigates fabrication and characterization approaches for the implementation of epitaxial graphene as an electronic material. The MRSEC has extensive collaborations with corporations, national laboratories and universities world-wide. Broad educational activities and outreach programs that integrate materials research into K-12, university and professional education are supported and fostered.

IRG 1, Epitaxial Graphene Electronics, focuses on developing epitaxial graphene (EG) as a new electronic material and is comprised of five thrusts: Graphene Growth; Graphene Chemistry; Materials Characterization; Electronic Properties; and Patterning, Devices, Architectures. The overall focus is on carbon-based electronics, in particular those made of epitaxial graphene (EG), which are leading candidates for the next generation of high-speed low-power nanoelectronics.

Harvard University - Materials Research Center
http://www.mrsec.harvard.edu/, Director: David Weitz

This MRSEC supports a broad interdisciplinary research program that investigates the mechanical properties of crystalline and glassy materials at scales intermediate between atomistic and continuum, focuses on and exploits digital, 3D assembly to develop novel materials, and explores innovative ways to make stimuli-responsive active materials by self-assembly of soft materials. The MRSEC operates a broad education and outreach research program that includes summer research experiences for undergraduates and teachers, activities for K-12 students, and programs to enhance the participation of members of underrepresented groups in science and engineering at the graduate, postgraduate level, and faculty levels. Three interdisciplinary research groups (IRG) and several innovative seed projects are proposed that will establish intellectual leadership in new fields:

IRG 1, Mechanics of Disordered Soft Materials, will investigate properties of soft materials that are subjected to very large deformations

IRG 2, Digital Assembly of Soft Materials, will develop the fundamental knowledge essential to create and rapidly transform diverse classes of soft materials into 3D functional architectures

IRG 3, Controlling and using Instabilities in Soft, Elastic Materials, will develop the science of SOFT (soft, non-linear, unstable, melded-function, and elastomeric) materials and use these material instabilities to develop devices with high-value performance at lower cost

University of Massachusetts-Amherst - Center for Polymer Science and Engineering
http://www.pse.umass.edu/mrsec/**, Director: Todd Emrick**

The UMass MRSEC on Polymers supports interdisciplinary research involving polymer chemistry, physics, and engineering. Interdisciplinary research group (IRG) topics collect teams of researchers focused on controlling nanoscale features of polymer assembly, and surface properties of polymers and nanocomposites. Seed projects focus on the impact of polymers on 2-D materials, and mechanical/chemical communication between polymer surfaces and live cells. The MRSEC has strong ties to industry through its industrial affiliates program, maintains effective education and outreach programs with emphasis on K-12 and teacher education, and supports outreach partnerships at nearby Smith College and Mt Holyoke College.

The MRSEC IRG projects are:

IRG 1, Directed Polymer-Based Assemblies. IRG 1 seeks to generate hierarchically-ordered polymer systems based on confinement and positional control over nanoscale elements. By directing polymer assembly, and by using the interactions between nanoscopic elements and a polymer host, the 2-D and 3-D spatial distribution, orientation and ordering of polymers can be manipulated to create novel architectures with exceptionally fine features without relying on external forces.

IRG 2, Polymer Surface Instabilities. IRG 2 aims to generate a new materials design paradigm that identifies elastic instabilities, specifically wrinkling, creasing, and crumpling, that control polymer surface morphology. Such instabilities produce new hierarchichal structures and exploit instability dynamics to generate rapid materials response.

Massachusetts Institute of Technology - Center for Materials Science and Engineering,
http://mit.edu/cmse/**, Director: Michael Rubner**

The underlying mission of the MIT MRSEC is to enable – through interdisciplinary fundamental research, innovative educational outreach programs, and directed knowledge transfer – the development and understanding of new materials, structures, and theories that can impact the current and future needs of society. The Center for Materials Science and Engineering (CMSE) works to bring together the large and diverse materials community at MIT in a manner that produces high impact science and engineering typically not realized through usual modes of operation. The Center has a strong education program directed toward graduate students, undergraduates, middle and high school students and K-12 teachers. Emphasis is placed on including underrepresented minorities in these programs. The Center operates widely accessible shared facilities and has an effective industrial outreach program. The following three IRGs are supported by the center.

IRG 1, Harnessing In-Fiber Fluid Instabilities for Scalable and Universal Multidimensional Nanosphere Design, Manufacturing, and Applications, explores fundamental issues associated with multi-material in-fiber fluid instabilities and uses the resultant knowledge to develop a new materials-agnostic fabrication approach for nanospheres of arbitrary size, geometry, and composition. This research will set the stage for discoveries, both fundamental and applied, spanning novel neuronal interface devices, delivery vehicles for pharmaceuticals, and potentially in the chemical and electronics industries.

IRG 2, Simple Engineered Biological Motifs for Complex Hydrogel Function, seeks to identify, engineer, and exploit the interplay of simple molecular motifs that are common to complex biological hydrogels. This research will enable the creation and control of complex biological hydrogel functions in synthetically accessible materials with potential impact in new fundamental materials design and biomedical and biological applications.

IRG 3, Nanionics at the Interface: Charge, Phonon, and Spin Transport, seeks to discover the coupling mechanisms between oxygen defects and the transport of phonons, spin, and charge at the interfaces of complex oxides. The resultant new knowledge will guide the design of materials for the next generation of miniaturized and high-efficiency devices for energy conversion and for information processing and storage.

University of Michigan - MRSEC for Photonic and Multiscale Nanomaterials,
http://cphom.engin.umich.edu/, **Director: Ted Norris**

The development of new materials has often proven to be the foundation for revolutionary advances in both science and technology; optical materials, for example, are key to high-speed data transmission, through such applications as diode lasers, modulators, detectors, and low-loss optical fibers. To those ends, the center's research activity is focused on two Interdisciplinary Research Groups (IRG's): wide-bandgap nanostructured materials for quantum light emitters and advanced electromagnetic metamaterials and near-field tools. The center is housed primarily at the University of Michigan; the Metamaterials IRG is a partnership between the University of Michigan and Purdue University. Other participating institutions include the University of Texas at Austin, University of Illinois Urbana Champaign, Wayne State University, and City College of CUNY.

IRG 1, Wide Bandgap Nanostructured Materials for Quantum Light Emitters, focuses on the development of nitride- and ZnO-based semiconductor quantum structures, establishing inorganic semiconductor nanophotonic structures with large bandgap and high exciton binding energy for high-efficiency light emitters, lasers, energy conversion, and other quantum devices. The research scope includes the epitaxy and synthesis of GaN-and ZnO-based nanostructures, their structural, electrical and optical characterization, and their application in laser spectroscopy and quantum optical studies, investigation of strong coupling phenomena, polariton lasing, high-efficiency visible LEDs, and microcavity lasers..

IRG 2, Advanced Metamaterials and Near-Field Tools, is focused on advanced electromagnetic metamaterials (MM's) and near-field tools. Metamaterials are nanostructured mixtures that behave as homogeneous optical materials with electromagnetic properties unattainable with naturally existing materials, such as negative refraction, cloaking, plasmonic hot spots, and super-resolution. This IRG investigates MM's – particularly chiral, quasiperiodic and hyperbolic MM's – and MM-inspired structures with unusual properties such as near-field plates and hyperlenses, and develops understanding leading to potential applications in communication, sensing, and imaging (notably sub-wavelength imaging).

University of Minnesota – Materials Research Science and Engineering Center
http://www.mrsec.umn.edu/index.php, Director: Timothy P. Lodge

The University of Minnesota (UMN) MRSEC unites distinguished senior and promising junior faculty from five departments in a multidisciplinary program to address fundamental issues spanning a wide spectrum of soft and hard materials. The topics to be addressed – all timely, intellectually rich, and technologically important – are sufficiently broad and challenging to require a team approach. Furthermore, as amply demonstrated over the previous award, the Center (*i*) fosters industrial involvement at an unprecedented scale, (*ii*) enables state-of-the-art Shared Facilities to be developed, maintained and made available to a national base of users, (*iii*) develops rewarding long-term partnerships with minority-serving institutions, (*iv*) supports ongoing, effective K-12 outreach activities involving thousands of younger learners every year. The MRSEC supports three IRGs; each IRG integrates the six basic elements of materials science and engineering – synthesis, theory, structural characterization, property evaluation, processing, and applications – required for effective innovation in materials research and development:

IRG 1, **Electrostatic Control of Materials,** will implement novel techniques for manipulation of charge carrier density at surfaces as a universal platform to probe and control electronic transport in new materials, thereby discovering new electronic phases, controlling functionality, and developing original device concepts.

IRG 2, **Sustainable Nanocrystal Materials,** will focus on the design, synthesis, processing, and thin film properties of environmentally benign, nanocrystal-based electronic and optoelectronic materials.

IRG 3, **Hierarchical Multifunctional Macromolecular Materials,** will develop a multiple interaction approach to polymer materials design that enables multifunctional applications by decoupling the optimization of two or more desired attributes.

University of Nebraska- Polarization and Spin Phenomena in Nanoferroic Structures (P-SPINS)

http://www.mrsec.unl.edu/, Director: Evgeny Tsymbal

The Nebraska MRSEC takes full advantage of UNL's collaborative group of scientists with exceptional expertise in fundamental properties of nanomaterials, functional heterostructures, and hybrid devices; newly constructed state-of-the-art research facilities; education and outreach infrastructure; and growing cohort of industry partners to explore emerging phenomena in nanoferroic materials whose unique electronic, magnetic, and transport properties offer exciting prospects for information processing; storage, generation, and distribution of electrical power; and advanced electronics. P-SPINS's education and outreach programs encourage gifted young people to pursue scientific careers, broaden the participation of underrepresented groups in science, and improve materials literacy among the general public.

Two Interdisciplinary Research Groups (IRGs) comprise the core of the Center:

IRG 1, Magnetoelectric Materials and Functional Interfaces, is focused on magnetoelectricity in complex functional heterostructures and its unconventional use beyond the realm of static equilibrium and linear response. This IRG synergistically explores dynamic strain-driven phase transitions in magnetoelectric bulk materials and thin films, voltage-controlled entropy changes, magnetoelectric heterostructures for ultra-low power devices with memory and logic functions, and electrical tuning of interface magnetic anisotropy and exchange bias.

IRG 2, Polarization-Enabled Electronic Phenomena, exploits ferroelectric polarization as a state variable to realize new polarization-enabled electronic and transport properties of novel oxide, organic, and hybrid heterostructures. This IRG investigates ferroelectrically induced resistive switching effects, modulation of electronic confinement at the hybrid ferroelectric/semiconductor and organic interfaces, dipole ordering in molecular ferroelectric structures, and manipulation of polarization-enabled electronic properties.

New York University – NYU Materials Research Science and Engineering Center

http://www.nyu.edu/as/mrsec/, Director: Michael Ward

The goals of the NYU MRSEC are straightforward – perform world-class research that cannot be performed by individual investigators alone, instill an interdisciplinary culture in graduate students and postdocs for thriving careers, and cultivate excitement in STEM among young scientists and engineers. The research mission of the NYU MRSEC revolves around two IRGs:

IRG 1, Random Organization of Disordered Materials*,* combines researchers from Chemistry, Civil and Chemical Engineering, Mathematics and Physics to investigate new principles for organizing and controlling the microstructure of multiscale materials. The IRG builds on the remarkable discovery of the *Random Organization Principle*, pioneered by NYU MRSEC investigators, by which systems driven out of equilibrium evolve towards absorbing states in which dynamic rearrangement ceases. IRG 1 explores the structures and correlations that arise in granular, multicomponent and active materials under external and internal driving, particularly those of the absorbing states, seeking to optimize material properties such as yield strength and photonic band structure, and to develop active materials such as optically reconfigurable colloids and active extensile viscoelastic liquids.

IRG 2, Molecular Crystal Growth Mechanisms*,* assembles a team from Chemical Engineering, Chemistry, Mathematics, and Physics to investigate the fundamental science of molecular crystal growth, an area of vital interest for pharmaceuticals, organic electronics, and other technologies. While crystal growth of metals, semiconductors, and binary oxides is highly developed, understanding of basic elements of molecular crystal growth is lacking. The IRG advances the understanding of essential aspects of crystal growth science and engineering, investigating nucleation, dislocation generation and structure, multi-step assembly at the unit cell level, and origins of non-classical morphologies in molecular crystals. This IRG combines theoretical modeling, computer simulation, and experiment to develop predictive models of crystal structure and free energy and to investigate the dynamic aspects of crystal growth.

Northwestern University - Multifunctional Nanoscale Material Structures,
http://www.mrsec.northwestern.edu/, Director: Mark Hersam

The Northwestern University Materials Research Science and Engineering Center (NUMRSEC) is a cross-disciplinary enterprise built on existing institutional strengths that supports innovative, leading-edge research and education. By addressing fundamental nanoscale materials science and engineering issues, the NU-MRSEC benefits society and the global community by providing a synergistic infrastructure in which to design, synthesize, and characterize transformative new materials and to explore new device concepts. The Center features a strong pre-college education program, including the widely disseminated Materials World Modules (MWM), as well as outstanding undergraduate and graduate educational opportunities. The science teachers who participate in the summer research program represent middle schools, high schools and community colleges and many actively collaborate with the Center throughout the school year. The MRSEC supports three IRGs:

IRG 1, Controlling Fluxes of Charge and Energy at Hybrid Interfaces, aims to establish fundamental structure-function relationships that govern the transport of charge carriers (electrons and holes), excitons (electron-hole pairs), and energy (vibrational or electronic) through multiscale materials with a particular focus on organic-inorganic interfaces within these materials and devices.

IRG 2, Fundamentals of Amorphous Oxide Semiconductors, seeks to develop one or more predictable models for the design and synthesis of complex amorphous oxide semiconductor (AOS) thin films with superior and unique optical, electrical, and thermal properties.

IRG 3, Plasmonically Encoded Materials for Amplified Sensing and Information Manipulation, seeks to manipulate light on the sub diffraction level, i.e. at a few nm to sub nm length scales.

Ohio State University – Center for Emergent Materials, http://cem.osu.edu/, Director: Chris Hammel

This MRSEC performs integrated research on emergent materials and phenomena creating new paradigms in computing and information storage. The research activities focus on a new understanding of electron-spin injection and transport, and the synthesis and exploitation of multifunctional properties of innovative double perovskite heterostructures. An important component of the education program is an interactive, constructionist approach to address the nature and cognitive cause of the misconception of materials science concepts. The MRSEC supports three IRGs:

IRG 1, Spin-Orbit Coupling in Correlated Materials: Novel Phases and Phenomena, is creating novel materials designed to tune the delicate interplay between electron correlations arising from Coulomb interactions and spin-orbit interactions that are enhanced in heavier elements. Their focus is on 5*d* materials where tuning by chemistry, structure and epitaxial strain enables topological phases, quantum phase transitions and novel magnetism.

IRG 2, Control of 2D Electronic Structure and 1D Interfaces by Surface Functionalization of Group IV Graphane Analogues, is creating new materials: single atom thick 2D materials reminiscent of graphene but composed of heavier group IV atoms. These allow tuning of electronic properties by covalently attaching surface species to enable novel electronic phases and spin physics. Spatially-patterning in 2D creates the exciting possibility of novel 1D interfaces.

IRG 3, Nonlinear Interactions Between Spin Flux and Engineered Magnetic Textures, is pushing spin transport studies into the nonlinear regime with a program that aims to understand spin fluxes interacting with magnetic textures. Nonlinear response could move beyond diffusive spin currents to enable novel approaches to spin manipulation and control for next generation spintronics.

University of Pennsylvania - Laboratory for Research on the Structure of Matter, http://www.lrsm.upenn.edu/, Director: Arjun Yodh

The LRSM MRSEC at the University of Pennsylvania was created by Penn in the early 1960's. Its mission is to discover new materials and identify innovative applications through collaborative, interdisciplinary research, including design, synthesis, characterization, theory & modeling of materials, broadly defined. The MRSEC integrates the design, synthesis, characterization, theory & modeling of materials ranging from hybrid macro-molecules and de novo proteins, with architectures & functions inspired by nature, to nano- and micro-structured hard & soft materials with unique properties. Potential practical outcomes are in the areas of drug delivery, energy transduction, electronics, optical signaling, sensors, and cellular probes. The MRSEC sustains an array of education and human resources development programs, whose impact will range from K-12 students and their teachers to undergraduates and faculty at minority serving institutions. The MRSEC has four interdisciplinary research groups (IRGs):

IRG 1, Geometric Routes to Soft Assembly & Dynamics, whose long term focus is to develop novel geometric routes to manipulate soft matter and thereby create new responsive materials and structures from complex fluids, embedded particles and proteins, micro-patterned substrates, and confining volumes.

IRG 2, Biologically-Inspired Janus-Dendrimer Assemblies, draws on synthetic expertise with dendrimers to assemble amphiphilic *Janus* dendrimers into membranes and icosahedral shells, and synthetic expertise with peptides to assemble "viral capsids" from peptide assemblies.

IRG 3, Mechanics of Disordered Packings, explores the mechanisms that lead to failure in disordered packings. It integrates theory with experiment to study the origins of failure in disordered systems across a range of constituent particle sizes, from atoms to nanoparticles to colloids to macroscopic grains. The IRG aims to achieve a fundamental understanding of the mechanical response of disordered packings which currently lags far behind our understanding of crystalline packings.

IRG 4, Controlled Function in Inter-Dimensional Materials, explores the complex interactions between low-dimensional constituents (nanoparticles) organized into higher-dimensional assemblies. This IRG aims to identify, understand, and ultimately exploit the novel collective interactions that arise in highly-ordered, multi-component materials assembled at the nanoscale. These materials are "inter-dimensional" in that complex interactions between low-dimensional constituents (nanoparticles) organized into higher-dimensional assemblies give rise to surprising and even transformative characteristics.

Penn State University – Center for Nanoscale Science,
http://www.mrsec.psu.edu/, Director: Vincent Crespi

The MRSEC supports a broad range of materials research encompassing studies and applications of biological and synthetic molecular motors, collective electronic and spintronic phenomena in restricted geometries, materials for the management of electromagnetic radiation, and multiferroics. The Center supports a full range of education activities ranging from the graduate level to K-12 teachers and students and education programs for the public. The Center for Nanoscale Science reaches deep into the pool of expertise present at Penn State and other key institutions to create teams to meet these goals. This cohesive culture of shared science is then extended to educate and inspire future scientists and members of the public, bring advances to market through industrial outreach, and reach the wider community through international collaboration and facilities networks. The MRSEC support four IRGs; each of the IRGs teams uses realistic theory to design compelling new systems that experimentalists can actually build, integrating the diverse forms of expertise necessary to conceive, implement and develop new classes of materials.

IRG 1, Designing Functionality into Layered Ferroics, has discovered 4 of the 6 main mechanisms of multiferroicity; it will greatly expand the palette of possible ferroics by activating broad new classes of layered materials through atomic-scale control over geometry, topology, composition, and gradients.

IRG 2, Powered Motion at the Nanoscale, pioneered the field of catalytic colloidal nanomotors; it will advance the field into new ground of collective phenomena and molecular-scale motility in active, powered materials that capture key elements of biological behavior in abiotic systems.

IRG 3, High-Pressure Enabled Electronic Metalattices*,* has developed a unique capability to fill ~10nm pores with high-quality crystalline semiconductors and characterize them with high-harmonic ultrafast coherent photons; it will deploy these techniques to create a new class of ordered 3D metalattices that modulate electronic, magnetic, and vibrational degrees of freedom against nm-scale structural order.

IRG 4, Multicomponent Assemblies for Collective Function*,* has established principles of optically modulated, gradient-driven assembly of heterogeneous, reconfigurable particle arrays; it will develop and deploy these techniques as a unique platform for random lasers and bioinspired optical sensors.

Princeton University – Princeton Center for Complex Materials,
http://www.princeton.edu/~pccm/, Director: N. Phuan Ong

The interdisciplinary research in the MRSEC at Princeton is focused on three directions in materials research. The first exploits recent advances in physics and chemistry to uncover novel “topological” quantum properties of electrons in semiconductors. The research is promising for enabling future electronics with ultralow heat dissipation, and enabling novel approaches to quantum computing. In the second direction, the researchers combine two new technologies that enable the growth of very thin polymer films with specialized physical properties critical for applications in many industries. The third direction seeks to control and manipulate the spin of a single electron trapped in an ultrathin nanowire. Advances will lead to logic elements for quantum computing as well as a new class of broadly tunable lasers. The researchers participate in a broad array of education projects. Each summer, several undergraduate students engage in supervised research in preparation for graduate school in science and engineering. In addition, the researchers host 18 high-school and 30 middle-school students from Central High, Trenton, for a rigorous 3-week science-camp (PUMA). The PUMA alumni have achieved a high-school graduation rate of 100%, with most going on to college. In addition, the researchers hold 8 one-day Science fairs each year (some co-organized with the town library) which attract from 300 to 800 K-12 students and their parents to campus. The MRSEC supports three IRGs:

IRG 1, Topological Phases of Matter and Their Excitations, brings together a diverse team comprised of solid-state chemists, condensed matter physicists, and electrical engineers to create materials systems with topological electronic phases and to probe and understand their novel properties using a variety of experimental and theoretical techniques. Specifically, they seek to test experimentally the new predictions, as well as to broaden the search for new 3D topological phases (such as Weyl metals and Dirac metals) and novel excitations (Majorana bound states and parafermions) in several materials. They also propose a new transport tool to probe "spin liquids" in frustrated magnets.

IRG 2, Structure and Dynamics in Confined Polymers, building on their researchers recent success in raising dramatically the glass-transition temperature in thin-film PMMA grown by a laser-ablation technique (MAPLE). Combining expertise in fluorescence, nanoscale imaging and simulation, they propose to investigate the 20-year riddle of why the thermodynamic and microstructural properties of confined, nanostructured, polymers differ dramatically from those in the bulk.

IRG 3, Development of Ultra-Coherent Quantum Materials, focuses on the problem of quantum computing, a major problem is maintaining quantum coherence in qubits that are well-separated. Here, they propose to exploit the coupling between spin qubits and microwave photons in a high-Q resonator to solve this problem. They also propose experiments to achieve very long spin coherence lifetimes in isotopically pure silicon.

University of Utah - Next Generation Materials for Plasmonics and Organic Spintronics
http://mrsec.utah.edu/, Director: Ajay Nahata

The primary mission of the University of Utah's MRSEC on Next Generation Materials for Plasmonics and Organic Spintronics' is to foster interdisciplinary basic research on new materials, develop the underlying theoretical and experimental science, train the next generation of scientists, create curiosity and excitement in Science, Math, and Engineering among the nation's youth, transmit the knowledge to the broadest possible segments of our society, and lay the foundation of the next generation science and technology that will revolutionize society. This will be accomplished through various research, educational and outreach programs under the MRSEC. The MRSEC is creating new knowledge in Plasmonics and Spintronics and transmit this to K-12 students, teachers, undergraduate and graduate students, postdoctoral fellows, as well as established researchers and scientists in academia. The MRSEC supports two IRGs:

IRG 1, Plasmonic Metamaterials from the Terahertz to the UV, focuses on Metamaterials that are artificially designed and structured materials, with unique functionalities not found in naturally occurring materials. This IRG aims to apply one of the main concepts of plasmonics, surface plasmon polaritons (SPP) in the THz and UV spectral ranges, with the aim of developing new basic science and technology in these under-developed spectral regions.

IRG 2: Organic Spintronics, is focused on understanding and manipulating spin excitations in Organic Semiconductors. Three spin-related organic devices will be studied: organic spin-valves, spin-OLEDs, and spin OPVs for solar energy conversion. Fundamental studies in magneto-conductance and magneto-EL in organic diodes will enhance our understanding of spin interactions in organics, such as hyperfine, spin-orbit and exchange.

University of Wisconsin-Madison - Nanostructured Materials and Interfaces, http://www.mrsec.wisc.edu/, Director: Nicholas Abbott

The Materials Research Science and Engineering Center at University of Wisconsin – Madison (UW MRSEC) is an integrated research and education Center that: i) promotes interdisciplinary research focused on synthesizing and understanding complex interfaces of materials systems with far-reaching impact in fields ranging from advanced electronics to biology, ii) is a national resource for education through the creation and dissemination of research-inspired educational materials for diverse audiences, iii) prepares the next generation of professionals through engagement in student leadership and mentoring, and professional development activities, iv) promotes diversity in STEM fields through effective diversity policy, its Partnership for Research and Education in Materials with University of Puerto Rico Mayaguez, and outreach programs that target all facets of the STEM education pipeline, and v) impacts economic development through knowledge transfer to the private sector.

The research goals of the UW MRSEC are to design, synthesize and understand material interfaces across a wide variety of platforms. It seeks to accomplish this through the creation of a regional network of leading materials researchers that come from 9 universities in the US, and an organizational strategy that encourages exploration and collaboration. The research of the UW MRSEC is organized into three interdisciplinary research groups (IRGs) and an interdisciplinary computational group (ICG):

IRG 1: New Materials from an Unstable World. This IRG's goal is to design and develop novel multinary materials that are thermodynamically unstable. The work centers on bismide semiconductors and InGaAsSbN materials, and is distinguished by the use of theory and experiment to elucidate non-equilibrium strategies for control of the nanostructure and properties of these complex materials.

IRG 2: Molecular and Electronic Dynamics at Organic-Inorganic Interfaces. IRG2 strives to understand the processes of electron transfer at interfaces and to exploit these processes in applications ranging from optoelectronics to photochemistry. The IRG is unique in possessing characterization tools that permit elucidation of dynamic molecular and electronic processes that occur over a remarkably wide range of temporal scales at these interfaces.

IRG 3: Functional Liquid Crystalline Assemblies, Materials and Interfaces. This IRG seeks to understand the role of liquid crystallinity in biological materials that perform complex functions, and to leverage that understanding to design new classes of functional liquid crystal-based materials. The research is distinguished by the synergistic study of bacterial materials and LC materials designed using an interplay mechanical stresses, defects and complex interfaces.

ICG: Interdisciplinary Computational Group. The goal of the ICG is to facilitate communication and synergies amongst computational researchers within the UW MRSEC and inspire new scientific and educational collaborations that cut across the research, education and outreach efforts of the IRGs and IEG.

Yale University – Center for Research on Innovative Structures and Phenomena, http://www.crisp.yale.edu/, Director: Charles Ahn

The Center for Research on Innovative Structures and Phenomena (CRISP) discovers and develops novel atomically engineered materials and processes based on a wide variety of materials and materials combinations that range from amorphous metals to artificially structured crystalline oxide heterostructures. This research also serves as an effective vehicle for student recruitment, retention, and education in Science, Technology, Engineering, and Mathematics (STEM). CRISP includes two interdisciplinary research groups (IRGs):

IRG 1, Atomic Scale Design, Control, and Characterization of Oxide Structures, where three grand challenges motivate the research: designing new interfacial systems that impart unique chemical and physical properties; creating new device paradigms based on the novel properties of complex oxide interfaces; and understanding and manipulating strongly correlated electrons in oxides. The IRG focuses on the novel chemical and physical phenomena that arise at atomically abrupt complex metal oxide interfaces. The group's expertise spans materials theory, atomically precise oxide interface formation, development and implementation of high-resolution real and reciprocal space imaging methods, and fabrication of electronic and optical devices.

IRG 2, Multi-Scale Surface Engineering with Metallic Glasses, where the grand challenge motivating this IRG is controlling surface properties through topographical structuring on multiple length scales to design functional materials. This goal is achieved using fabrication techniques based on nano-imprinting and blow molding of metallic glasses that were pioneered at Yale. These techniques allow hierarchical structuring of metallic surfaces ranging from the atomic scale to tens of micrometers. Materials discovery is key to achieving this grand challenge, which is driven by combinatorial synthesis and characterization strategies paired with theoretical modeling.

For additional information:

- Visit http://www.mrsec.org, or the web sites of the individual Centers;
  Visit http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5295&org=DMR&from=home

- Contact the NSF Program Director:

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- Contact the MRSEC Director (see information below)

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