"CCMR aims to be a world leader in the design, control, and understanding of the behavior of both crystalline and disordered nanomaterials."

Dan Danowski/CCMR

Francis DiSalvo
Director, CCMR; Chemistry and Chemical Biology

Cornell Center for Materials Research

Advancing the Understanding of the Behavior of Nanomaterials and Designing New Ones

The mission of the Cornell Center for Materials Research (CCMR), established in the early 1960s, is to explore, advance, and exploit the forefront of the science and engineering of advanced materials. The unifying theme of the center's current research is the study of materials purposefully structured at the nanoscale (near atomic dimensions). This objective is pursued through experimental and theoretical studies of the assembly and processing of nanomaterials and their resulting behavior. CCMR aims to be a world leader in the design, control, and understanding of the behavior of both crystalline and disordered nanomaterials.

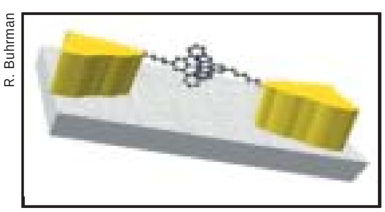
CCMR's research is organized around five interdisciplinary research groups; four smaller groups, called "seeds"; and eight shared experimental facilities with specialized, sophisticated equipment to further the center's collective goals. Approximately 100 faculty members from nine departments are active members of CCMR, and about half of them received direct research support from the center last year. CCMR has active and innovative educational programs for schoolteachers, children, undergraduates, and the community. The center also has a growing number of industrial partnerships and collaborations.

Peer-reviewed and competitively selected interdisciplinary research groups are composed of 7 to 10 faculty participants from several departments, along with associated postdoctoral and student researchers. Highlights of several key projects of CCMR's five interdisciplinary research groups are presented here, selected from the great breadth of research in progress at the center.

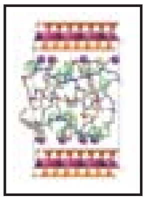
Nanostructured Materials: Electron and Spin Transport

Nanostructured electronic and magnetic materials are essential for the future implementation of advanced devices for computing and communication. These materials exhibit unusual properties not found in larger systems, and sometimes they even exhibit novel phenomena. Such nanodevices can be used to probe the behavior of larger devices, such as devices on microchips, and to explore, in exquisite detail, fundamental behavior of materials. Robert A. Buhrman, Applied and Engineering Physics, leads this group in exploiting advanced materials processing and pushes lithography to its ultimate limits, extending the state of the art to produce devices that isolate specific electronic or magnetic features for detailed study. The program seeks to understand electronic transport and spin interactions on the mesoscopic, as well as the microscopic level. Central to this effort is the development of novel nanoscale probes and the application of high-resolution scanning probe electron microscopy to allow the determination of the atomic and electronic structures that result in the observed behavior.

R. Buhrman



Nanofabricated gold electrodes

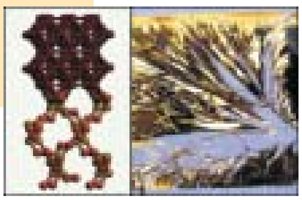


E. Giannelis

Polymer interspersed between layers of a clay-like material

Nanoscale Polymer-Inorganic Hybrid Materials

Fundamentally new and often superior physical properties emerge in hybrid materials when nanoscale heterogeneity is introduced. This group, led by Emmanuel P. Giannelis, Materials Science and Engineering, and Dotsevi Y. Sogah, Chemistry and Chemical Biology, exercises molecular-level control over the macroscopic properties of polymer-inorganic hybrid materials through the synergistic combination of novel synthetic strategies, molecular-level physical measurements, and molecular modeling and theory. Current research is focused on understanding the kinetics of formation of the composites, the dynamics of the polymer component above and below the bulk glass transition temperature, and the thermodynamic driving forces and stability of the resulting composites. By exploiting a variety of exciting new synthetic approaches, it now appears possible to prepare nanocomposites of almost any polymer, including commodity polymers such as polyethylene and polypropylene.

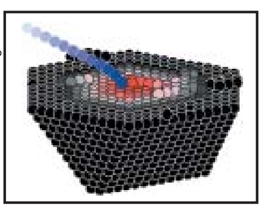


S. Baker

Copper film on a glassy substrate

Oxide Glasses: Surfaces and Thin Film Interfaces

The properties and near-surface chemistry of glass surfaces frequently determine the behavior of other materials in intimate contact with glass. Very little is known about glass surfaces, which generally have properties and compositions different from bulk glasses due to cooling, processing, and interactions with the environment. Few tools have been developed to characterize these surfaces and their interactions with deposited thin films. Beginning with the “simplest” of oxide glasses, John M. Blakely, Materials Science and Engineering, and Neil W. Ashcroft, Physics, have led this group in finding large and unexpected changes in near-surface properties when silicon dioxide is modified to produce useful engineering glasses based on the $CaO\text{-}Al_2O_3\text{-}SiO_2$ (calcium-aluminum-silicon) system. Ultra-high vacuum atomic force microscopy, a novel ultra-high vacuum scanning tunneling microscope system for nearly insulating surfaces, tracer diffusion, and high-resolution scanning transmission electron microscopy are being used to provide microscopic insights into the observed surface composition modification due to processing as well as the atomic-level details of surface chemistry and bonding to metal and semiconductor films. Theoretical studies of the structural and electronic features of glass surfaces and thin films, essential to forming a detailed model of the behavior in these complex systems, are being carried out to complement this effort.



J. Engstrom

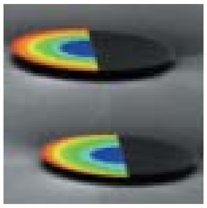
Energetic atomic collisions with a surface

Fundamentals of Energetic Surface Processing

The fabrication of electronic and magnetic devices on the nanoscale requires control over processing parameters that determine the chemical composition, structure, trapped defects, and morphology on this length scale. Such devices are most often produced by deposition of atoms or small clusters of atoms onto various substrates. These deposition processes include chemical vapor deposition, sputtering, and evaporation. The processes can be modified by adding a beam of atoms or ions of controlled energy in the 1 to 100 eV (electron volts) energy range, or the growth can be derived directly from such an energetic beam in the absence of the other processes. By exploiting the interaction of the energetic beam with the growing surface, significant changes in the film chemistry and morphology can be introduced and controlled to produce desired characteristics. The group, led by Joel D. Brock, Applied and Engineering Physics, and James R. Engstrom, Chemical and Biomolecular Engineering, seeks a fundamental understanding of the deposition and etching processes that produce these characteristics. Highly focused and high-intensity x-ray beams at the Cornell High Energy Synchrotron Source (CHESS) provide unprecedented insight to these subtle and complex growth processes.

Dynamic Mechanical Properties of Nanoscale Materials

M. Hines



SEM of “mushroom” resonators

All materials can be made to vibrate at a natural resonant frequency that increases as the size of the system decreases. For example, the frequencies achievable in nanomechanical resonators could enable the creation of novel devices that are useful in communications systems. At the nanoscale, however, a variety of new and incompletely understood phenomena become apparent in such resonators. The objective of this group, led by Melissa A. Hines, Chemistry and Chemical Biology, and Jeevak M. Parpia, Physics, is to understand, model, and control these phenomena by developing and exploiting both nanofabrication techniques available at the Cornell Nanofabrication Facility (CNF) and by strong coupling to advanced theoretical computations and modeling. Current research makes clear that atomic-level control of the surface morphology and chemistry and of bulk defects is essential to achieving reproducible and optimal device performance.

Francis J. DiSalvo
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Associate Director of the Cornell Center for Materials Research and Director of CCMR Facilities

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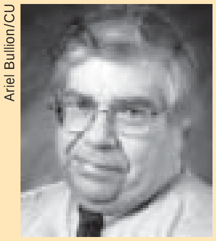


Robert Buhrman, Applied and Engineering Physics

Nanostructured Materials: Electron and Spin Transport Implementing advanced devices for computer and communication

Jon Reis/PHOTOLINK

Dotsevi Sogah, Chemistry and Chemical Biology

Nanoscale Polymer-Inorganic Hybrid Materials Preparing nanocomposites of polymers, such as commodity polymers—polyethylene and polypropylene

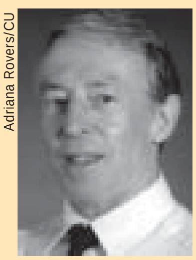
Emmanuel P. Giannelis, Materials Science and Engineering, and Dotsevi Y. Sogah, Chemistry and Chemical Biology

Oxide Glasses: Surfaces and Thin Film Interfaces Exploring technologies that are key to the computer display industry and emerging fields

Robert Barker/CU

Neil Ashcroft, Physics

Adriana Rovers/CU



John Blakely, Materials Science and Engineering

Frank DiMeo/CU

Joel Brock, Applied and Engineering Physics

Jon Reis Photography

James Engstrom, Chemical Engineering

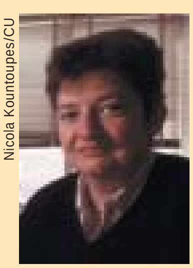
Fundamentals of Energetic Surface Processing Seeking an understanding of the deposition and etching processes that are key to the fabrication of electronic and magnetic devices at the nanoscale, important for new technologies in electronics and biotechnology

Dynamic Mechanical Properties of Nanoscale Materials Studying frequencies in nanomechanical resonators for the creation of novel devices useful for communications systems

Rodney Bowman

Jeevak Parpia, Physics

Nicola Kountoupes/CU



Melissa Hines, Chemistry and Chemical Biology