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Division of Materials Research

Cornell Center for Materials Research

Director:
Prof. Frank DiSalvo
(607) 255-4272
director@ccmr.cornell.edu

Associate Director:
Dr. Helene Schember
(607) 255-4274
helene@ccmr.cornell.edu

FAX	(607) 255-3957
Website	http://www.ccmr.cornell.edu
Address	627 Clark Hall of Science Cornell University Ithaca, NY 14853

2: Executive Summary

The Cornell Center for Materials Research

The mission of the Cornell Center for Materials Research (CCMR) is to advance, explore and exploit the forefront of the science and engineering of advanced materials. The unifying theme of our current research is the study of materials purposefully structured at the nanoscale (near atomic dimensions). Our aim is to be world leaders in the design, control and understanding of the behavior of both crystalline and disordered nano-materials. This objective is pursued through fundamental experimental and theoretical studies of the assembly and processing of nano-materials and of their resulting behavior.

The Center is an integral element of Cornell's outstanding international research reputation and its strong engineering and physical science departments. It continues to play a leading role in fostering the long tradition of interdepartmental, interdisciplinary cooperation and collaboration and in increasing such interaction with outside organizations. Eighty-eight faculty members from ten departments are active members of CCMR; forty-one received direct research support from the MRSEC program last year. Such support generally provides funds for a graduate student or post-doctoral researcher to work collaboratively in the focus area of a particular group. The MRSEC research is organized around five Interdisciplinary Research Groups (IRGs), five smaller groups (Seeds) and eight facilities that utilize specialized, sophisticated equipment to further our collective goals. CCMR also has an active and innovative Educational Outreach program as well as an effective and growing Industrial Outreach activity.

The Center's research activities are primarily supported by the National Science Foundation's Division of Materials Research, but also by generous contributions from Cornell University, by critical Industrial grants and gifts, the Department of Education, and most recently by New York State. The University provides all the funding for the Center's administrative staff, five full graduate fellowships, partial support for Seed projects as well as partial (50%) tuition for all supported graduate students and direct cash for some of our capital equipment expenditures.

The MRSEC's research thrusts are:

IRG-A – Nanostructured Materials: Electron and Spin Transport. Nanostructured electronic and magnetic materials are essential for the future implementation of advanced devices for computing and communication. Such materials exhibit unusual properties not found in larger systems and sometimes even novel phenomena. These nano-devices can also be used not only to probe the behavior of larger devices, such as devices on microchips, but also to explore, in exquisite detail, fundamental behavior of materials. This IRG exploits 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 aims 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. Recent advances include the invention of single molecule transistors and of silicon nano-transistors.

IRG-B – Nanoscale Polymer – Inorganic Hybrid Materials. Fundamentally new and often superior physical properties emerge in hybrid materials when nanoscale heterogeneity is introduced. This group 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 nano-composites of almost any polymer, including commodity polymers such as polyethylene and polypropylene. Finally, the group is exploring methods to produce magnetic or conducting composites by controlled formation and inclusion of different nano-structured inorganic phases. Recent advances include the development of a high temperature process to produce polymer nano-composites.

IRG-C – 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, yet very little of a fundamental nature is known about glass surfaces. Beginning with the "simplest" of oxide glasses, IRG-C has found large and unexpected changes in near surface properties when SiO_2 is modified to produce useful engineering glasses based on the $CaO-Al_2O_3-SiO_2$ system. UHV-AFM, a novel UHV-STM system for nearly insulating surfaces, tracer diffusion, and high resolution STEM 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. Recent discoveries include the essential role of impurities in determining the bonding of metals to glass.

IRG-D – 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. Deposition processes include chemical vapor deposition, sputtering, evaporation, etc. These processes can be modified by adding a beam of atoms or ions of controlled energy in the 1 to 100 eV energy range, or the growth can be 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. Through a combined experimental and theoretical effort, the group seeks a fundamental understanding of the deposition and etching processes that produce these characteristics. The use of highly focused and high intensity X-ray beams at the Cornell High Energy Synchrotron Source (CHESS) is providing unprecedented insight to these subtle and complex growth processes. Recent advances include the ability to grow and monitor the growth of complex oxides one atomic layer at a time.

IRG-E – Dynamic Mechanical Properties of Nanoscale Materials. 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 nano-mechanical resonators could enable novel devices useful in communications systems. However, at the nanoscale a variety of new and incompletely understood phenomena become apparent in such resonators. The objective of this group is to understand, model and control these phenomena by developing and exploiting both nano-fabrication techniques available at Cornell's 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, as well as of bulk defects, is essential to achieving reproducible and optimal device performance. In collaboration with the Naval Research Laboratory, recent experiments with diamond nano-webs have produced the highest frequency mechanical resonators known.

Seed groups are composed of a few researchers focused on an emerging scientific or technological area that appears to have potential for future growth into a larger activity, perhaps a new IRG. The five current Seed projects are (briefly described in Section 4):

- Dimensional Evolution of Materials
- Morphology and Electrical Properties of Vacuum Deposited Organic Semiconductor Films
- Synthesis of Hybrid Organic-Inorganic Porous Materials and Applications in Catalysis
- Ordered Macromolecular Structures by Physicochemical Triggering
- A ß-SiC Electro-optic Switch for High Speed Si-Based Photonic Circuits

Shared Experimental Facilities are crucial to the study of complex materials and our interactions with industry. The CCMR's eight facilities comprise an integrated system for materials synthesis and preparation, analysis, testing and characterization, together with an advanced research computing capability. They are used not only by CMMR researchers, but also by researchers campus-wide, from other universities, and from government and industrial laboratories. Student users are trained in the use of these sophisticated capabilities. Other on-campus facilities are central to our mission as well, especially the Cornell Nanofabrication Facility (CNF) and Cornell High Energy Synchrotron Source (CHESS).

An essential and outstanding feature of CCMR is our **Educational Outreach** activity. Last year, 30 programs were offered, several lasting for 6-10 weeks, focusing on upstate NY students (K-12), parents and teachers (K-college), as well as on undergraduates from across the country. Many Cornell faculty (including many non-CCMR members), postdocs, graduate and even Cornell undergraduate students are important contributors to this highly successful program. The graduate students in particular are enthusiastic and effective ambassadors for science in both our campus programs and in traveling to regional schools to work with students and teachers. We are building the outreach culture into our graduate education so that all scientists understand their role and responsibility in helping the nation become scientifically literate.

Industrial outreach: Cornell and CCMR are committed to ensuring that technical innovations and inventions move efficiently from the research bench to the private sector and to developing productive industrial partnerships. Many industrial collaborations grow directly out of the ongoing research in our IRGs and Seeds, but some are nucleated by industrial partners or by others on campus. Our very successful Polymer Outreach Program (POP) is now 14 years old and provides not only important "bench to bench" collaborations with R&D personnel in industry but also research support for graduate students and postdocs.

The Center is managed by a Director, Frank DiSalvo, an Associate Director, Helene Schember and an Executive Committee that is elected by the CCMR membership, as well as by the (co)leaders of the IRGs and Seeds.