Electron-beam Microcharacterization Centers

Portfolio Description

This activity supports three electron-beam microcharacterization centers, which operate as user facilities, work to develop next-generation electron-beam instrumentation, and conduct corresponding research. These centers are the Electron Microscopy Center for Materials Research at Argonne National Laboratory (ANL), the National Center for Electron Microscopy at Lawrence Berkeley National Laboratory (LBNL), and the Shared Research Equipment program at Oak Ridge National Laboratory (ORNL). Operating funds are provided to enable expert scientific interaction and technical support and to administer a robust user program at these facilities, which are made available to all researchers with access determined via peer review of brief proposals. Capital equipment funding is provided for instruments such as scanning, transmission, and scanning transmission electron microscopes; atom probes and related field ion instruments; related surface characterization apparatus and scanning probe microscopes; and/or ancillary tools such as spectrometers, detectors, and advanced sample preparation equipment.

Unique Aspects

Electron probes are ideal for investigating local structure and chemistry in materials because of their strong interactions with atomic nuclei and bound electrons, allowing signal collection from small numbers of atoms–or, in certain cases, just one. Furthermore, the use of these charged particles allows electromagnetic control and lensing of electron beams resulting in spatial resolution that can approach single atomic separations or better (i.e., approaching or exceeding 0.1 nm; the world-leading Transmission Electron Aberration-corrected Microscope (TEAM) instrument at NCEM is capable of 0.05 nm direct spatial resolution). The BES electron-beam characterization user facilities provide unparalleled access to specialized equipment and expert staff and develop next-generation instrumentation and characterization techniques. They make these capabilities available to the scientific community on the basis of submitted proposals and at no cost to non-proprietary users, and are the only facilities of this type focused on electron-beam characterization that are available in the nation.

Relationship to Others

These activities couple with many others in BES programs and enable a broad range of research across numerous fields, including physics, chemistry, and materials science, within national laboratory programs as well as for academic and other scientists. The most direct relationship is with the BES Electron and Scanning Probe Microscopies research program; operation of the Electron Beam Microcharacterization Centers was part of this program, then referred to as Structure and Composition of Materials, prior to FY 2007. There are also strong interactions with other BES user facilities, particularly with the collocated Nanoscale Science Research Centers. The electron beam centers support use by researchers funded by BES, by other parts of the Office of Science, by other parts of the Department of Energy, and by numerous other federal agencies as well as industry.

Significant Accomplishments

Major historical accomplishments for the electron-beam characterization centers have spanned instrumental improvements in resolution and other performance measures, development of unique capabilities, and outstanding scientific results. This includes the development and operation of the Atomic Resolution Microscope (in the early 1980s) and One-Ångstrom Microscope (in the late 1990s) at NCEM, followed by the multi-laboratory project to create the TEAM instrument (completed in 2009); all constituted world-leading instruments in demonstrated lateral spatial resolution. Extensive in-situ work and new technique development, including real-time observation of radiation damage in materials and the demonstration of scanning confocal electron microscopy, has been carried out using unique facilities at EMC. The SHaRE program has emphasized chemical identification and spectroscopy, with notable achievements in pinpointing the elemental segregation phenomena leading to brittleness or toughening behavior at ceramic interfaces and in developing and using novel methods and tools such as atom location by channeling-enhanced microanalysis (ALCHEMI) and the laser-assisted local electrode atom probe (Laser LEAP). Recent advances across this suite of facilities have included detection of picometer-scale strain relaxation in magnetic nanoparticles leading to core-shell segregation and catalytic surface activity, and development of new approaches to characterize magnetic spins and other properties at higher spatial resolution than was previously possible.

Mission Relevance

Electron scattering allows the capture of meaningful signals from very small amounts of material, including single atoms under some circumstances. Electron beam characterization therefore provides unsurpassed spatial resolution and the ability to simultaneously get structural, chemical, and other types of information from sub-nanometer regions, allowing study of the fundamental mechanisms of catalysis, energy conversion, corrosion, charge transfer, magnetic behavior, and many other processes. All of these are fundamental to understanding and improving materials for energy applications and the associated physical characteristics and changes that govern performance.

Scientific Challenges

A wide variety of major scientific challenges that could be uniquely or most effectively addressed by electron scattering methods have been delineated in workshops on future science needs and opportunities for the field, including broad BES-sponsored workshops and facility-driven meetings focused on the TEAM project, in-situ approaches, soft matter and soft/hard interface characterization, and other topics. These challenges include:

- Investigating synthesis and assembly of nanomaterials
- Clarifying size effects on thermodynamic properties of nanostructures
- Direct comparison of theory and experiment at the nanoscale through the determination of the three-dimensional atomic-scale structure of nanostructures
- Determining the nanoscale origins of macroscopic properties, such as strength and conductivity, for high-performance materials ranging from those used in structural applications to those used in microelectronics
- Understanding the roles of individual atoms, point defects, and dopants in materials, such as in GaN for solid-state lighting or the role of oxygen in high-temperature superconductivity

- Characterization of interfaces in materials at arbitrary orientations, between ordered and disordered materials, and at hard/soft interfaces and phase boundaries
- Mapping of electromagnetic (EM) fields in and around nanoscale matter, including the atomic-scale origins of magnetism at the nanoscale
- Probing structures in their native environments, including atomic-scale investigation of functioning catalysts, corrosion processes, oxidation, biomaterials, and organic-inorganic interfaces
- Explaining the behavior of matter far from equilibrium, such as dynamic/transient behavior and environments involving high radiation, pressure, or temperature
- Development of tools to probe soft and biological matter without damaging/destroying samples

Projected Program Evolution

Full user operations are expected to continue at all three of these facilities, which are routinely available to users during normal working hours. The Transmission Electron Aberration Corrected Microscope (TEAM) instrument at the National Center for Electron Microscopy at LBNL will, in addition, be available to the research community for extended hours. This instrument was developed as a DOE Major Item of Equipment project and completed in FY 2009. It leads the world in spatial resolution and embodies the first chromatic aberration corrector in an instrument of this kind, and thus its availability opens new frontiers in imaging of materials on the nanoscale for the broad scientific community. Further program evolution will be driven by the scientific challenges described above and will require corresponding instrumental and technique improvements including work on in-situ environments; advanced electron, photon, and x-ray detectors; better temporal resolution; improved and specialized electron sources; electron optical configurations designed for interrogating materials under multiple excitation processes; and community software tools including virtualized instruments and improvements in remote operation.