Electron-beam Microcharacterization Centers

Portfolio Description

The electron-beam microcharacterization centers (EBMCs) operate as national user facilities and work to develop next-generation electron-beam scattering and diffraction instrumentation, and conduct corresponding research. One-of-a-kind signature and world-class instrumentation are available including scanning, transmission, and scanning transmission electron microscopes; atom probes and related field ion instruments; related surface characterization apparatus; scanning probe microscopes; ancillary tools such as spectrometers, detectors, and advanced sample preparation equipment. These facilities are routinely made available on a scientific merit basis to the broad research community.

There are three EBMCs:

- Electron Microscopy Center for Materials Research (EMC) at Argonne National Laboratory (ANL)
- National Center for Electron Microscopy (NCEM) at Lawrence Berkeley National Laboratory (LBNL)
- Shared Research Equipment (ShaRE) program at Oak Ridge National Laboratory (ORNL).

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, a single one. Furthermore, the use of these charged particles allows electromagnetic control and lensing of electron beams resulting in spatial resolution better than interatomic separations (i.e., approaching or less than 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. The EBMCs have a broad range of capabilities and are accessible without usage fees for non-proprietary work, with instrument time and staff support allocated on the basis of peer review of proposals.

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 prior to FY 2007, called the Structure and Composition of Materials program at that time.
- There are also strong interactions with other BES user facilities, particularly with the collocated Nanoscale Science Research Centers. The electron beam centers are used by

researchers funded by BES, other parts of the Office of Science, other parts of the Department of Energy, and numerous other federal agencies and industry.

- BES coordinates nanoscience activities with other federal agencies through the National Science and Technology Council (NSTC) Nanoscale Science, Engineering, and Technology subcommittee, which leads the National Nanotechnology Initiative.

Significant Accomplishments

Major historical accomplishments for the electron-beam characterization centers have spanned improvements in resolution and other performance measures, development of unique capabilities, and outstanding scientific results.

- 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) are such examples; all constituted world-leading instruments in demonstrated lateral spatial resolution. TEAM 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.
- 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, have 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 the suite of EMBC 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:

- Determining the atomic and nanoscale origins of macroscopic properties, for developing new high-performance materials ranging from those used in structural applications to those used in microelectronics
- Elucidating the underlying science involved in chemical processes such as catalysis and charge transport
- Probing the interfaces between hard and soft matter in operating 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

A BES workshop will be held in February 2014 on the "Future of Electron Diffraction and Scattering" to identify the scientific frontiers that are addressable by the next generation of electron probes.

Projected Program Evolution

The EBMCs are in full operation phase and the scientists have established significant major capabilities and leadership in several areas of electron probe science and characterization. They work effectively with the large user community, and their collocated NSRC (Nanoscale Science Research Center) and beam facilities. 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; high 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. There is strong mission alignment and scientific complementarity between the EBMCs and NSRCs. As such, the EBMCs will merge with their respective collocated NSRCs in FY 2015 to produce combined nanoscience research capabilities that are unique in the world.