Research Activity: **Electron-beam Microcharacterization Centers**
Division: Scientific User Facilities
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Portfolio Description:

This activity supports three electron-beam microcharacterization user centers: the National Center for Electron Microscopy (NCEM) at Lawrence Berkeley National Laboratory (LBNL); the Electron Microscopy Center for Materials Research (EMC) at Argonne National Laboratory (ANL); and the Shared Research Equipment Program (SHaRE) at Oak Ridge National Laboratory (ORNL). These centers contain a variety of highly specialized instruments to provide information on the structure, chemical composition, and properties of materials from the atomic level on up, using direct imaging, diffraction, spectroscopy, and other techniques based primarily on electron scattering. They accommodate over 500 users annually and also participate in leading-edge instrument development. These three facilities, along with other BES-funded efforts, have collaborated on the Transmission Electron Aberration-corrected Microscope (TEAM) major item of equipment project to develop a next-generation platform for electron microscopy and an initial instrument optimized for high resolution and atomic tomography, which will be sited at NCEM and available to users by the end of FY 2009.

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 TEAM instrument 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 Structure and Composition of Materials program, of which this was a part 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.

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-Angstrom Microscope (in the late 1990s) at NCEM, followed by the multi-laboratory project to create the TEAM instrument (which will conclude in 2009); all constituted world-leading instruments in demonstrated lateral spatial resolution. Extensive in-situ work on radiation damage in materials has been done in unique facilities at EMC, which has operated several TEMs attached directly to ion accelerators. 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 local electrode atom probe (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:

Atomic arrangements, local bonding, defects, interfaces and boundaries, chemical segregation and gradients, phase separation, and surface phenomena are all aspects of the nanoscale and atomic structure of materials, which ultimately control their mechanical, thermal, electrical, optical, magnetic, and many other properties and behaviors. Understanding and control of materials at this level is critical to developing materials for and understanding principles of photovoltaic energy conversion; hydrogen production, storage, and utilization; catalysis; corrosion; response of materials in high-temperature, radioactive, or other extreme environments; and many other situations that have direct bearing on energy, environmental, and security issues.

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 and on planning for the TEAM project. 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

Funding Summary:

Dollars in Thousands

	FY 2007	FY 2008	FY 2009 Request
Electron Beam Centers	8,040	8,183	11,250
TEAM Project	5,508	6,687	0

Projected Program Evolution:

The electron-beam characterization facilities were previously supported within BES research programs and were transitioned in FY 2007 to scientific user facilities, with corresponding formal responsibilities for both scientific excellence and user productivity and satisfaction. Further development will be driven by the scientific needs of users and will involve suitable renewal of instrumentation and a continued increase in interactions with other BES user facilities. The TEAM project has resulted in substantial advancements, including the creation of a dramatically different specimen stage configuration that offers more precise, stable, and flexible sample handling and manipulation, as well as the first implementation of chromatic aberration correction in transmission electron microscopy. The use of this instrument offers improved performance and new kinds of experiments; furthermore, there is the potential for developing additional instruments that use these platform technologies and are tailored for specific kinds of research (e.g., in-situ processing or fields, spectroscopy, etc.). 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.