

X-ray Light Source Facilities

Portfolio Description

This activity supports the operation of five x-ray light sources. Four of the light sources are storage ring-based sources: the Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory (LBNL), the Advanced Photon Source (APS) at Argonne National Laboratory (ANL), the National Synchrotron Light Source-II (NSLS-II) at Brookhaven National Laboratory (BNL), and the Stanford Synchrotron Radiation Lightsource (SSRL) at SLAC National Accelerator Laboratory (SLAC). The fifth light source, the Linac Coherent Light Source (LCLS) at SLAC, is a free-electron laser that provides laser-like radiation in the x-ray region of the spectrum, with 10 orders of magnitude greater peak power and brightness than the most powerful storage ring-based light sources. The newly constructed NSLS-II, which has replaced NSLS, started operation in FY 2015 to enable the study of material properties and functions at the nanoscale level and to provide the world's finest x-ray imaging capabilities.

Scientific Challenges

First, the facilities must be operated optimally, which means optimizing instrument-hours of operation, not just accelerator-hours of operation, and making the instruments widely available to the general user community. Second, optimal utilization of the LCLS coherent short-wavelength x-ray source will require continued development of new capabilities and advanced optics, instruments, and detectors.

Projected Evolution

X-ray scattering will continue to play a central role in the growth of BES programmatic science. The facilities will need continuous growth and advancement in terms of upgrades, new instruments, and increased availability of user time. The set of instruments associated with these facilities provides unique scientific and technical capabilities, rarely available in other parts of the world. These facilities need to be kept in an optimal operational condition in order to maintain and increase the tremendous scientific achievements they have facilitated.

The LCLS has properties vastly exceeding those of storage ring-based light sources in three key areas: peak brightness, coherence, and ultrashort pulses. The peak brightness of the LCLS is 10 orders of magnitude greater than current synchrotrons; the light is coherent or "laser like" enabling many new types of experiments; and the pulses are short (~50 femtoseconds in standard operation with improvements that can further reduce the pulse length to <5 femtoseconds), enabling studies of fast chemical and physical processes. These characteristics open new realms of scientific applications in the chemical, material, and biological sciences including fundamental studies of the interaction of intense x-ray pulses with simple atomic systems, structural studies on single nanoscale particles and biomolecules, ultrafast dynamics in chemistry and solid-state physics, studies of nanoscale structure and dynamics in condensed matter, and use of the LCLS to create plasmas.

Significant Accomplishments

During the past three decades, BES has been the nation's major supporter of x-ray light sources. BES support pioneered new storage ring lattices for improved beam stability and brightness; developed insertion devices that provide 10 to 12 orders of magnitude greater brightness than the best conventional x-ray sources; and discovered or developed such powerful experimental techniques as magnetic x-ray scattering, microbeam diffraction, x-ray microscopy, photoelectron spectroscopy and holography, x-ray nanoprobe, full-field and

diffraction imaging, synchrotron x-ray scanning tunneling microscopy, rapid acquisition pair distribution function, inelastic x-ray scattering using nuclear resonances, extended x-ray absorption fine structure, and near-edge x-ray absorption fine structure. The newly constructed light source, NSLS-II, has successfully commissioned and delivered x-rays to general users through routine top-off operation.

Recent accomplishments at the light source facilities include:

- At the Stanford Synchrotron Radiation Lightsource, researchers developed a new fabrication method to produce advanced x-ray diffractive nanostructured devices for high-resolution, high-efficiency manipulation of hard x-rays. At the Advanced Photon Source, scientists developed a new multilayer grating interferometer that was used to produce high-quality x-ray phase-contrast images. These new optical devices have significantly enhanced the imaging quality at the BES light sources.
- A new resonant soft x-ray scattering technique was developed at Lawrence Berkeley National Laboratory's Advanced Light Source to determine the 3-D structure and chemical composition of novel polymer films formed by directed self-assembly. The results of these new measurements will guide improvements in the directed self-assembly process to assist the semiconductor industry in the development of high-volume, cost-effective semiconductor manufacturing at the nanoscale.
- Time-resolved soft x-ray transmission microscopy measurements revealed the strength and duration of trains of electric and magnetic pulses affecting the circulation of a magnetic vortex that may lead to the possibility of magnetic memory bits with four states instead of two, improving storage capacity as well as energy efficiency.
- Scientists at NSLS-II developed a hard x-ray scanning microscope employing novel nanofocusing optics that produces a tiny x-ray beam with unprecedented spatial resolution. The microscope provides researchers a unique capability that opens up new scientific frontiers of high-resolution x-ray imaging, taking full advantage of the brightness of NSLS-II. This development won a 2016 Microscopy Today Innovation Award and a 2016 R&D 100 award.

Unique Aspects

The BES light sources are the most advanced facilities of their kind in the world. Together, they served over 11,000 users in FY 2016 from academia, Department of Energy (DOE) national laboratories, and industry, a number that has increased at a very fast pace in the past decade. As current facilities and those under construction are fully instrumented, this number could continue to grow at this fast rate in the next decade. These light sources represent the largest collection of such facilities operated by a single organization in the world. Conception, design, construction, and operation of these facilities are among the core competencies of the BES program.

Mission Relevance

These facilities were born from the most fundamental of needs, i.e., the need to characterize materials at the atomic and molecular level. In order to understand, predict, and ultimately control materials properties, it is necessary to determine the atomic constituents of materials, the positions of the atoms in materials, and how the materials behave under the influence of external perturbations such as temperature, pressure, magnetic or electric field, and chemical change. A large number of experimental and theoretical tools are used to achieve these ends. In the last two decades, the experimental demands have motivated the development of large-scale powerful facilities that are too complex and expensive to develop, construct, and operate by individual institutions and/or companies. Such highly sophisticated tools are by their nature centralized and

staffed with specialists who provide expertise to the user community to optimize the scientific use of the facility. The development, construction, and operation of these facilities are one of the most important missions and core competencies of BES. The scientific accomplishments of these facilities are reflected in the large number of publications appearing annually in the most important scientific journals.

Relationship to Other Programs

- This activity has very strong interactions with all BES programmatic research that uses x-ray light sources. This includes research in atomic physics, condensed matter and materials physics, chemical dynamics, catalysis, geosciences, high-pressure science, environmental sciences, engineering, biosciences, and much more.
- Interaction also exists with other parts of the Office of Science, notably the Office of Biological and Environmental Research and the Office of Fusion Energy Sciences, and with other areas of DOE, notably the National Nuclear Security Administration, the Office of Energy Efficiency and Renewable Energy, Office of Nuclear Energy, and the Office of Environmental Management.
- There are frequent contacts with other federal agencies in order to better coordinate efforts in optimizing beamlines and instruments. This activity is establishing more frequent contacts with international user facilities such as the European Synchrotron Radiation Facility (ESRF) in France, European X-Ray Free Electron Laser (XFEL) in Germany, Super Photon Ring-8 GeV (Spring-8) in Japan, Positron Elektron Tandem Ring Anlage III (PETRA III) in Germany, and others. The objectives are to share experiences and to make optimal use of present facilities.