

The ALS—A High-Brightness XUV Synchrotron Radiation Source*

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Abstract

The Advanced Light Source (ALS) at the Lawrence Berkeley Laboratory is scheduled to be operational in the spring of 1993 as a U.S. Department of Energy national user facility. The ALS will be a next-generation source of soft x-ray and ultraviolet (XUV) synchrotron radiation. Undulators will provide high-brightness radiation at photon energies from below 10 eV to above 2 keV; wiggler and bend-magnet radiation will extend the spectral coverage with high fluxes approaching 20 keV. The ALS will support an extensive research program in which XUV radiation is used to study matter in all its varied gaseous, liquid, and solid forms. The high brightness will open new areas of research from the materials sciences, such as spatially resolved spectroscopy, to the life sciences, such as x-ray microscopy with element-specific sensitivity. Experimental facilities (insertion devices, beamlines, and end stations) will be developed and operated by participating research teams working with the ALS staff.

I. INTRODUCTION

Synchrotron radiation is usually the tool of choice for researchers interested in spectroscopy and scattering experiments in the ultraviolet or x-ray regions of the spectrum. Indeed, the availability of intense, tunable, collimated, polarized radiation has driven the evolutionary development of dedicated facilities optimized for the generation of synchrotron radiation. By 1993, so-called third-generation synchrotron sources will be coming on line in the United States, Europe, and Asia [1].

Exceptionally high spectral brightness (flux per unit area of the source, per unit solid angle of the radiation cone, and per unit bandwidth) is the new feature of the third-generation synchrotron facilities. The storage rings at these facilities are designed to optimize brightness in two ways. First, the rings contain lengthy straight sections to accommodate long undulators up to 5 meters in length with up to 100 or so periods. In most circumstances, both photon flux and undulator brightness increase linearly with the number of periods. Second, the rings are designed to have electron (or positron in some cases) beams with a small emittance. Since the size and divergence of the electron beam set lower bounds for the radiation-source size and divergence, a low-emittance electron beam translates directly into a high-brightness undulator photon beam.

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The combination of a very-low-emittance storage ring with optimized undulators makes possible the generation of radiation with a spectral brightness that is a factor of 20 or more greater than that obtainable from second-generation sources, depending on the spectral range (Figure 1). In the past, order-of-magnitude increases in brightness have led to qualitatively new developments in spectroscopic and structural studies of both gas-phase and condensed matter [2].

Most directly benefiting from high brightness are researchers in both the life and physical sciences who hope to achieve enhanced spatial resolution down to distance scales of about 100 Å in x-ray microscopy and spatially resolved XUV spectroscopy. An example of the latter arises from the study of solid surfaces, which are mostly heterogeneous, making interpretation of spectroscopic data obtained from illuminating the entire surface difficult. With spatial resolution, spectral features could be directly associated with specific surface areas and structures.

For the spectroscopist, the benefits of brightness are equally

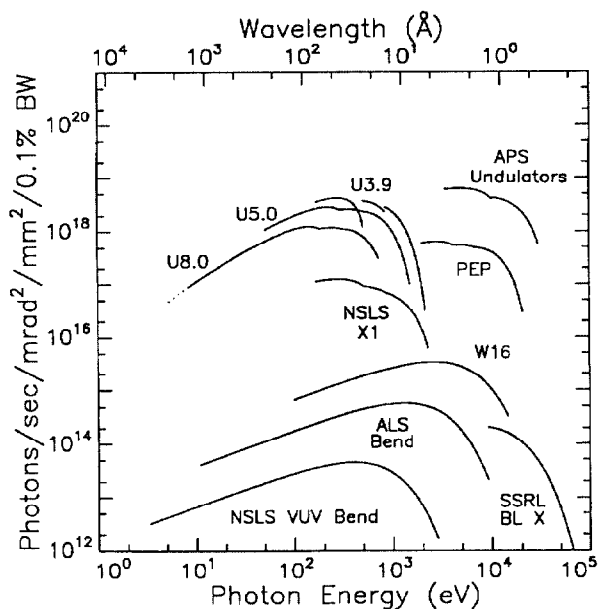


Figure 1. The spectral brightness envelopes are shown for three ALS undulators, an ALS wiggler, the ALS bend magnets, undulators planned for the Advanced Photon Source (APS), and representative insertion-device and bend-magnet sources at the National Synchrotron Light Source (NSLS) and the Stanford Synchrotron Radiation Center (SSRL and PEP). The discontinuities in the undulator curves represent a shift from the envelope of the fundamental to that of the third harmonic, etc.

substantial. Brightness leads to high spectral resolution without the usual penalty of reduction in signal and increase in measuring time. Experiments with once impracticably long measuring times, perhaps because of inherently weak signals, now become reasonable to contemplate.

Finally, brightness and the naturally pulsed nature of synchrotron radiation permit observation of short-lived or transient systems by means of time-resolved spectroscopic, scattering, and imaging experiments. The ultimate time resolution, achievable when there are enough photons in a single pulse of bright synchrotron light to generate a useful signal, would be to follow events in real time on the sub-nanosecond time scale.

II. THE ADVANCED LIGHT SOURCE

The ALS is under construction in Berkeley, California, at the Lawrence Berkeley Laboratory (LBL) of the University of California. The ALS is a U.S. Department of Energy-funded construction project with a total estimated cost of \$99.5 million. Congress has already appropriated 93 percent of this amount, and the remainder is in the President's fiscal year 1992 budget. The project is scheduled to be completed in April 1993. As a national user facility, the ALS will be available to visiting and in-house researchers from university, industrial, and federal laboratories.

The ALS facility consists of an accelerator complex, a complement of insertion devices, beamlines, and associated experimental apparatus, and a building to house this equipment [3, 4]. The state-of-the-art (low-emittance) storage ring has 10 straight sections available for insertion devices (undulators and wigglers). Initially, 24 high-quality bend-magnet ports will also be available. The undulators will generate high-brightness radiation at photon energies from below 10 eV to above 2 keV in the XUV region of the spectrum [5]. The wigglers will access the hard x-ray region by generating broad-band radiation up to 20 keV. Bend magnets will be useful below 10 keV. Infrared

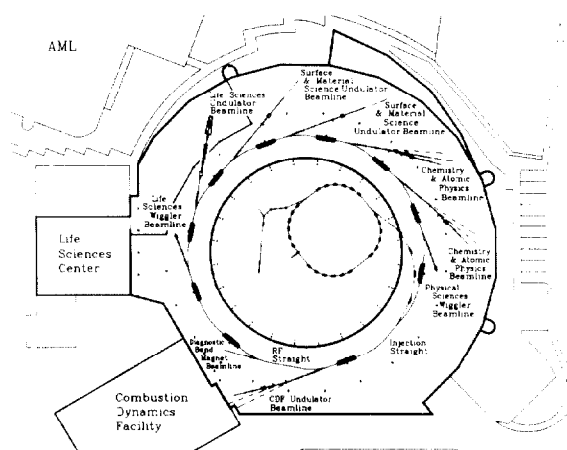


Figure 2. Floor plan showing a possible placement of insertion devices and locations of associated beamlines in the ALS building. The maximum beamline length is about 35 m. The prime bend-magnet ports to be developed initially are located in the center bend magnet of each storage-ring arc. At two ports per magnet, there is a total of 24 ports.

radiation will also be available from the bend magnets. In the normal operating mode, the time structure of the radiation will comprise pulses with a full-width-half-maximum of about 30 ps and separation of 2 ns.

These capabilities will support an extensive research program in a broad spectrum of scientific and technological areas in which x-ray and ultraviolet radiation is used to study and manipulate matter in all its varied gaseous, liquid, and solid forms. The ALS will also serve those interested in developing the fabrication technology for micro- and nanostructures, as well as for characterizing them.

Table 1. Insertion-Device Participating Research Teams (PRTs)

Insertion Device	Scientific Focus	Spokesperson
U10.0	Chemical dynamics	Tomas Baer, U. of North Carolina
U8.0	Atoms, molecules, ions	Denise Caldwell, U. of Central Florida
U8.0	Pump-probe, timing, dynamics experiments	R. Stanley Williams, U. of California, Los Angeles
U5.0	Surfaces and interfaces	Brian Tonner, U. of Wisconsin-Milwaukee
U5.0	Surfaces and interfaces	Joachim Stöhr, IBM Almaden Research Center
U3.9	X-ray imaging and optics for the life and physical sciences	Stephen Rothman, U. of California, San Francisco
W16	Atomic, molecular, optical physics; materials science	Bernd Crasemann, U. of Oregon Philip Ross, LBL
W16	Life sciences	Stephen Cramer, U. of California, Davis

Table 2. Bend-Magnet Participating Research Teams (PRTs)

Scientific Focus	Spokesperson
Soft x-ray spectroscopy and time-resolved studies; x-ray optics	James H. Underwood, LBL
EUV spectroscopy and time-resolved studies; x-ray optics	James H. Underwood, LBL
Infrared spectroscopy and time-resolved studies; fast IR detectors	Gwyn P. Williams, Brookhaven National Laboratory
Polarized photon studies: accelerator and beam diagnostics, spin-dependent interactions with matter, chiral biological molecules	Mervyn Wong, LBL
Photoemission spectroscopy; interfaces, thin films, and multilayers optical component characterization	Marvin J. Weber, Lawrence Livermore National Laboratory
High-energy chemical physics; surfaces, interfaces, and nanostructures; electrochemistry	David A. Shirley, LBL

III. SCIENTIFIC PROGRAM

The initial scientific program emphasizes the high brightness of XUV light available from the ALS. The program is being implemented by means of participating research teams (PRTs) consisting of investigators with related research interests from one or more institutions. The primary responsibility for experimental apparatus rests with the PRTs; the responsibility for the beamlines and, where appropriate, insertion devices will be shared between the ALS and the PRTs. In return for its commitment, each PRT receives a guaranteed fraction of the ALS operating time at its beamline. A substantial fraction of the time at each beamline will also be made available through a proposal process to independent investigators not affiliated with a PRT.

PRTs working with undulator or wiggler beamlines are called insertion-device teams; those working with bend-magnet beamlines and are known as bend-magnet teams. A Call for Proposals issued in the spring of 1989 resulted in 18 proposals from both insertion-device and bend-magnet teams. Nine insertion-device teams, which subsequently coalesced into the eight that are listed in Table 1, were approved in December 1989. Figure 2 shows a layout of the ALS building with possible locations of insertion devices and associated beamlines. Six bend-magnet teams that were approved in June 1990 and May 1991 are listed in Table 2. Including three additional ports allocated to insertion-device teams, seven of the 24 available prime bend-magnet ports have been spoken for.

Some of these groups are expected to use the high brightness of the ALS undulators to open new areas of research in the materials sciences, such as spatially resolved photon and electron spectroscopy (spectromicroscopy). Biological applications will include x-ray microscopy with element-specific sensitivity in the water window of the spectrum (23-44 Å) where water is much more transparent than protein, thereby allowing soft x-rays to penetrate the natural aqueous environment of these systems. The ALS will also be an excellent research tool for atomic physics and chemistry because the high flux will allow measurements to be

made with tenuous gas-phase targets. The short pulse width (30-50 ps) will facilitate time-resolved experiments. A future option is the construction of special devices to generate radiation with a controlled elliptical polarization [6].

Major research areas proposed for ALS undulator beamlines include: (1) soft x-ray microscopy of materials, surfaces, and biological systems, (2) spatially resolved spectroscopy of materials, surfaces, and biological systems, (3) high-resolution soft x-ray spectroscopy of materials and surfaces, (4) soft x-ray gas-phase spectroscopy of atoms and molecules, (5) molecular spectroscopy and dynamics with synchrotron radiation/laser pump-probe methods, (6) spin-polarized photoemission spectroscopy, and (7) polarization-dependent experiments, such as circular dichroism of biological systems.

Wiggler-based x-ray studies will include spectroscopy of atoms in both the gas phase and in condensed matter, spatially-resolved elemental analysis with an x-ray microprobe, grazing-incidence x-ray scattering from surfaces, and x-ray diffraction of large biological molecules (protein crystallography). Bend-magnet research will include studies of physical and biological systems with polarized radiation and with infrared radiation.

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