LBL-31243

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Accelerator & Fusion Research Division

Presented at the 4th International Conference on Synchrotron Radiation Instrumentation, Chester, United Kingdom, July 15–19, 1991, and to be published in the Proceedings

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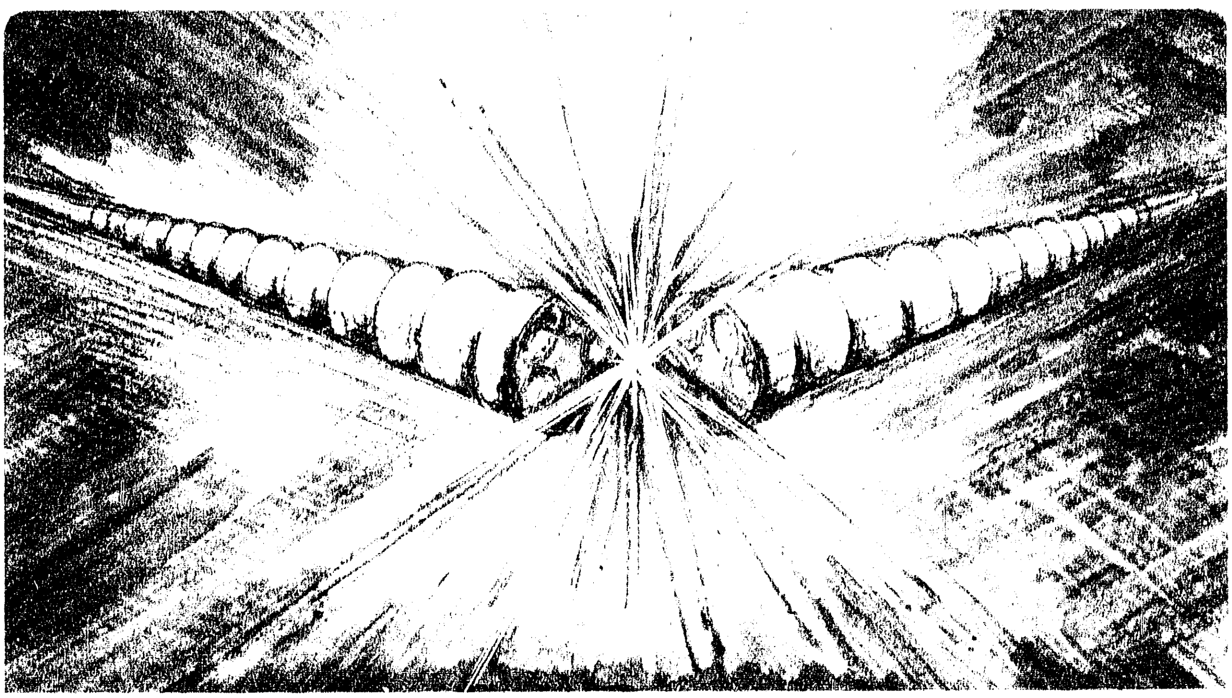
September 1991



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

LBL--31243

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THE ADVANCED LIGHT SOURCE AT THE LAWRENCE BERKELEY LABORATORY*

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*This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098

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Abstract

The Advanced Light Source (ALS) at the Lawrence Berkeley Laboratory (LBL),scheduled to be operational in the spring of 1993 as a U.S. Department of Energy national user facility, will be a next-generation source of soft x-ray and ultraviolet (XUV) synchrotron radiation. Undulators will provide the world's brightest synchrotron 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 above 10 keV. These capabilities will support an extensive research program in a broad spectrum of scientific and technological areas in which XUV 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.

I. INTRODUCTION

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 driving construction of third-generation synchrotron facilities around the world.[1] The storage rings at these facilities are designed to optimize brightness in two ways. First, the rings are designed to have electron or positron beams with a very low emittance (typically $<10^{-8}$ meter-radians). Since the size and divergence of the beam set lower bounds for the radiation-source size and divergence, low-emittance translates directly into a high-brightness undulator photon beam. Second, the rings contain lengthy straight sections to accommodate long undulators up to 5 meters in length with as many as 100 periods. In most circumstances, both photon flux and undulator brightness increase approximately linearly with the number of periods. 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]

II. OVERVIEW OF THE ADVANCED LIGHT SOURCE

The ALS facility consists of an accelerator complex consisting of a 50-MeV electron linear accelerator, a 1-Hz, 1.5-GeV booster synchrotron, and an electron storage ring; a complement of insertion devices, beamlines, and associated experimental apparatus; and a building to house this equipment.[3] Although the energy of the storage ring will range from 1 to 1.9 GeV, its performance is optimized at 1.5 GeV. In the normal operating mode, the time structure of ALS radiation will comprise pulses with a full-width-half-maximum of about 30 ps and separation of 2 ns. Of the 12 straight sections in the storage ring, ten are available for undulators and wigglers up to 4.5 m in length. Of the maximum of 48 bend-magnet ports, 24 are so-called prime ports with superior properties and will be developed first.

Figure 1 shows the spectral brightness of three undulators (U8.0, U5.0, and U3.9, where the number refers to the period length in centimeters) when the ALS operates at 1.5 GeV.[4,5,6] To cover the photon-energy range from 10 eV to above 2 keV, it is planned to use the fundamental and the third and fifth harmonics of each undulator (see Table I). Between them, the undulators will be able to excite the K shell of elements through silicon and the L shell of elements up to krypton in the periodic table. A future option is the construction of special devices to generate radiation with a controlled elliptical polarization. The wiggler in Figure 1 generates a broad continuous spectrum characterized by a critical photon energy ε_c of 3.1 keV, thereby extending the ALS spectral range into the hard x-ray region above 10 keV. The critical photon energy of the bend magnets is 1.56 keV. Because it is difficult to fabricate aspheric optical surfaces sufficiently accurately to take full advantage of the undulator source, the strategy for the initial ALS-constructed beamlines is to use spherical surfaces for all mirrors and gratings and to actively water-cool the optics.[7,8]

III. SCIENTIFIC PROGRAM

Under construction at LBL with a total estimated cost of $99.5 million, the ALS 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 initial scientific program emphasizes the high brightness of XUV light available from the ALS. 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.

ALS user 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.

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. Both undulator and bend-magnet beamlines will be used to develop the x-ray lithography and characterization technology for advanced integrated circuits and other nanostructures.

IV. ACKNOWLEDGEMENT

This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Division of Materials Sciences, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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Table I. Parameters for ALS insertion devices.

Name	Period [cm]	No. of periods	Photon energy range [eV][a]	Critical energy [keV]
Undulators				
U10.0	10.0	45	—[b]	—
U8.0	8.0	55	5.4–220	—
			[16.2–660]	
			[27–1100]	
U5.0	5.0	89	52–380	—
			[156–1140]	
			[260–1900]	
U3.9	3.9	115	169–500	—
			[507–1500]	
			[845–2500]	
Wiggler				
W16	16.0	16	—	3.1

[a]The photon energy range of the fundamental and of the third and fifth harmonics (shown in brackets) when the electron-beam energy is 1.5 GeV.
[b]Only the range from 6 to 50 eV in the fundamental will be used.

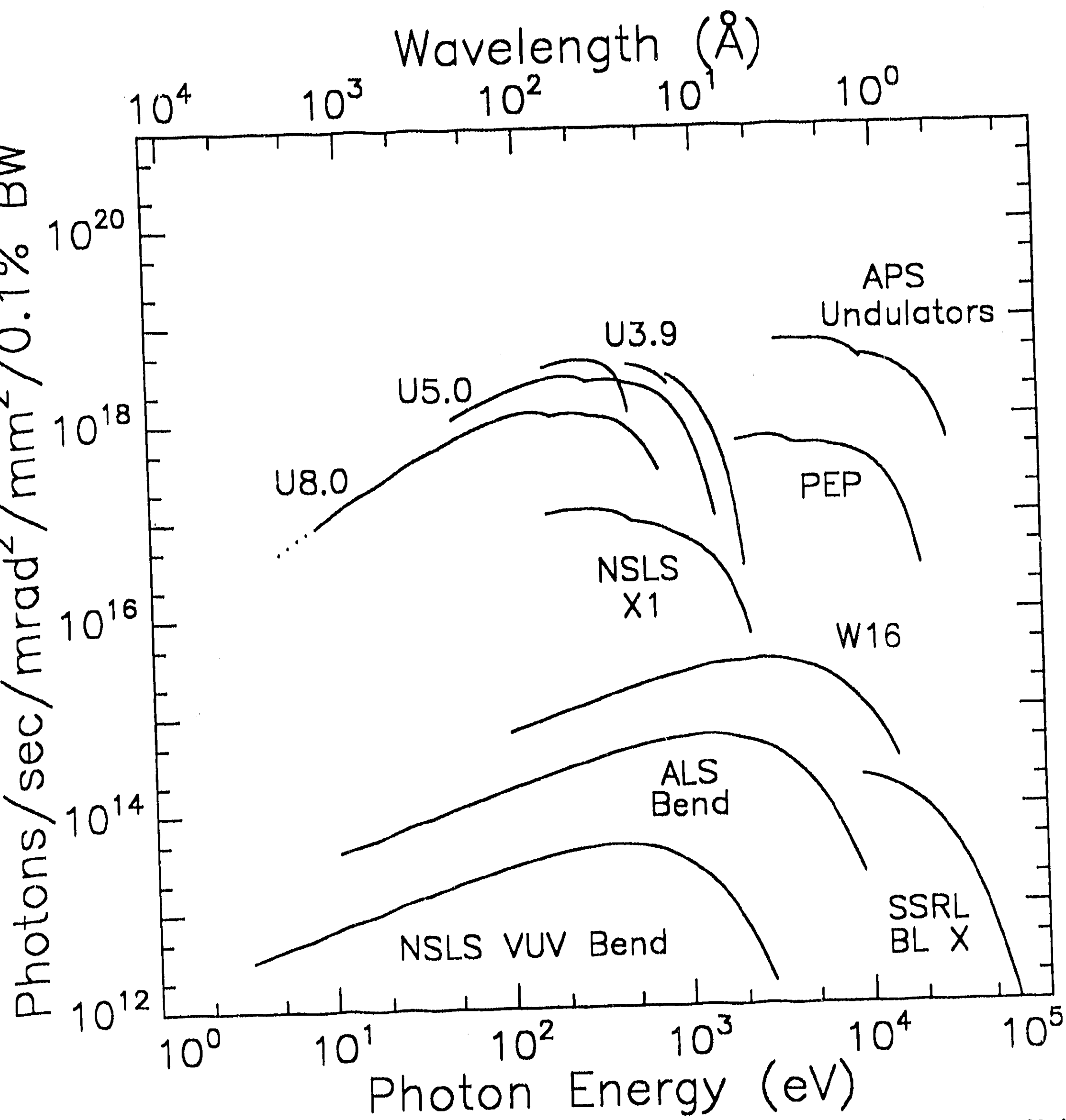

FIG. 1. Spectral brightness as a function of photon energy for three ALS undulators, the ALS wiggler, the ALS bending magnets, undulators planned for the Advanced Photon Source (APS), and representative insertion-device and bend-magnet sources at the National Synchrotron Light Source (NSLS) and the Stanford Synchrotron Radiation Center (SSRL). The discontinuities in the undulator curves represent a shift from the envelope of the fundamental to that of the third harmonic, etc.

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