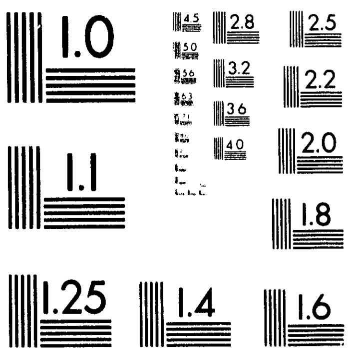
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THE STANFORD SYNCHROTRON RADIATION LABORATORY
- 20 YEARS OF SYNCHROTRON LIGHT-

KATHERINE CANTWELL
Stanford Linear Accelerator Center, Stanford Synchrotron Radiation Laboratory
Stanford, CA 94309-0210 USA

ABSTRACT

The Stanford Synchrotron Radiation Laboratory (SSRL) is now operating as a fully dedicated light source with low emittance electron optics, delivering high brightness photon beams to 25 experimental stations six to seven months per year. On October 1, 1993 SSRL became a Division of the Stanford Linear Accelerator Center, rather than an Independent Laboratory of Stanford University, so that high energy physics and synchrotron radiation now function under a single DOE contract. The SSRL division of SLAC has responsibility for operating, maintaining and improving the SPEAR accelerator complex, which includes the storage ring and a 3 GeV injector.

SSRL has thirteen x-ray stations and twelve VUV/Soft x-ray stations serving its 600 users. Recently opened to users is a new spherical grating monochromator (SGM) and a multi-undulator beam line. Circularly polarized capabilities are being exploited on a second SGM line. New YB_{66} crystals installed in a vacuum double-crystal monochromator line have sparked new interest for Al and Mg edge studies. One of the most heavily subscribed stations is the rotation camera, which has been recently enhanced with a MAR imaging plate detector system for protein crystallography on a multipole wiggler. Under construction is a new wiggler-based structural molecular biology beam line with experimental stations for crystallography, small angle scattering and x-ray absorption spectroscopy. Plans for new developments include wiggler beam lines and associated facilities specialized for environmental research and materials processing.

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THE STANFORD SYNCHROTRON RADIATION LABORATORY

- 20 YEARS OF SYNCHROTRON LIGHT -

1993 marks 20 years since the first synchrotron light was extracted from SPEAR, and the second year of SSRL's operation as a fully dedicated synchrotron radiation facility. The laboratory, which in 1973 was known as SSRP (the Stanford Synchrotron Radiation Project), began as a single experimental station housed in a small shed adjacent to the SLAC high energy physics storage ring, SPEAR. Initially funded by the National Science Foundation, by 1977 there were two beam lines in operation with ten experimental stations, and the synchrotron radiation user community had become firmly established.

SSRL originally ran very successfully in a mode parasitic to the high energy physics program on SPEAR. However, the Nobel-prize winning discovery by the high energy physicists of the Ψ particle led to the operation of SPEAR at 1.5 and 1.8 GeV, too low an energy to produce hard x-rays. In response to this SSRP proposed to include a wiggler beam line in the 1977 expansion program funded by the NSF. In 1978 the first wiggler was tested and the insertion-device era began. In 1979 SPEAR was committed to dedicated synchrotron radiation production for 50% of its operating time. SSRL was transferred to the DOE in 1982, as it continued to grow beyond the scope of a traditional NSF project. In 1986 it became clear to SSRL, and to the DOE that an independent injector was needed for SPEAR if SSRL was to meet its users needs. The $13M injector project was completed in the fall of 1990. Simultaneously, the high energy physics program was terminated on SPEAR, as the Beijing BEPC ring, which SLAC had helped design, was commissioned and superceded SPEAR for high energy physics research. In 1991 SSRL began a new era as a fully dedicated synchrotron radiation light source.

Since the completion of the injector SSRL has concentrated on improving the reliability and performance of SPEAR as a light source. This effort will continue over the next few years as major upgrades are done to the SPEAR power supplies, computer and other infrastructure.

The new SSRL accelerator complex proved itself in 1993. The dedicated SPEAR injector system consists of a short linear accelerator with a beam energy of 100-150 MeV, a 3 GeV booster synchrotron and a beam transport line. [1] In 1993 SPEAR operated seven months for synchrotron radiation users in a 130 nm-rad low emittance lattice with a fill current of 100 mA. The product of beam lifetime and current reaches 2.2 - 2.8 Ah (*i.e.*, more than 20 hrs lifetime at 100 mA and more than 40 hrs at 50 mA). Typically the ring is refilled once every 24 hours. SPEAR reliability was exceptionally high with a 89.5% delivery of scheduled user beam over the entire period. The beam was used by 550 users running 325 experiments.

Experimental Facilities

MATERIALS/X-RAY FACILITIES AT SSRL

SSRL provides 13 x-ray stations, eleven of which are general user beam lines and eight of which have insertion device sources. Most of the stations are general purpose, with the exception of a dedicated Huber diffractometer on a wiggler beam line and a white-light bending magnet station. Since many of the stations have been in existence for some time efforts are presently concentrated on making significant upgrades. Retrofitting with larger "walk-in" hutches and silicon mirrors is underway on a number of stations.

Beam line 10 (National Laboratories/University of California/SSRL PRT) based on a 31-pole wiggler is an extremely intense source of x-rays. [2] It has a large rear hutch, and the PRT recently developed a versatile x-ray diffraction end station based upon a Huber diffractometer with an extra 2Θ detector arm. This diffractometer is designed to accommodate a helium cryostat, high-temperature furnaces, high-pressure cells, or small vacuum chambers and can be configured for 2Θ scan, energy-dispersive, or image plate detection of powder or single-crystal patterns.

A new in-vacuum beam path and monochromator system has been completed on the 54-pole wiggler end station, 6-2 (EXXON/LBL/SSRL PRT beam line). The beam line was rebuilt to contain an in-vacuum monochromator system, a post-monochromator harmonic rejection and vertical focusing Ni-coated mirror, a thin (5 mils) Be window as the only absorber in the beam line and located at the user end of the entire optics system, and associated differential pump section, vacuum, beam line and ring control systems. The station now provides very high intensity (about 10^2-10^3 more photons/sec than previously) in the 2.1-4.0 keV region.

For several years SSRL has been studying the effects of high-power x-ray beams on optical components such as mirrors and monochromator crystals. Water-cooling schemes for crystals incorporating internal cooling channels have been tested on SSRL and CHESS wiggler beam lines, showing cooling improvement by more than an order of magnitude over side-cooling methods. SSRL has recently placed an order with Rockwell Power Systems for two monochromator crystals utilizing a pin-post water cooling scheme. The improved cooling at SSRL Beam Line 10-2 should increase the experimental count rates by at least a factor of three.

STRUCTURAL MOLECULAR BIOLOGY FACILITIES AT SSRL

SSRL is particularly strong in the area of structural molecular biology, which comprises about one-third of the SSRL user program. A number of dedicated facilities exist to support research in the areas of protein crystallography, x-ray absorption spectroscopy and small-angle x-ray scattering.

Protein crystallographic facilities at SSRL include: (1) a rotation camera facility on the 8-pole wiggler station 7-1. This facility includes a MAR Research Imaging Plate X-ray Data Collection system which incorporates a single-crystal monochromator and a 30 cm diameter imaging plate recording camera/scanner as well as a liquid nitrogen cryostat for data collection at cryogenic temperatures; (2) a multi-wire proportional counter area detector system for MAD phasing experiments on Station 1-5; (3) a CAD-4 diffractometer on Station

1-5; (4) a white beam Laue diffraction camera and associated experimental apparatus for time-resolved crystallographic studies that can be used on the 31-pole wiggler station; and (5) a Fuji off-line imaging plate scanner.

X-ray absorption spectroscopy facilities include two Canberra 13-element Ge array detectors, two Oxford Instruments liquid helium continuous flow cryostats, remotely-controlled optical alignment rails, several ionization chamber fluorescence detectors and associated electronics. There are up to 9 experimental stations available for EXAFS experiments at SSRL, with the 8-pole wiggler station, 7-3, currently being dedicated as an EXAFS station with a fixed cryostat/Ge detector/rail setup.

Small-angle x-ray scattering facilities include a remotely-controlled scattering/diffraction camera including either a linear one-dimensional position sensitive proportional counter or a quadrant detector. The camera has a vacuum beam path with a number of possible path lengths. Capabilities also exist for rapid mixing (minimum time scale 10-50 msec) with a computer-controlled system. The camera is quasi-permanently installed on the 8-pole wiggler station 4-2.

VUV/Soft X-ray Facilities at SSRL

The number of VUV/soft x-ray beam lines has grown in number and complexity over the years. Currently, there are 12 experimental stations in this region of the spectrum. Several of the original monochromators, *e.g.*, the grasshoppers, are still in use, however, the majority of the beam lines have either been improved to include new capabilities or are beam lines based on modern designs.

In the photon energy range below 200 eV, SSRL has two TGMs (stations 1-2 and 8-1) and a Seya-Namioka monochromator (station 3-2) on bending magnet lines. The use of the Seya has decreased due to the introduction of the TGMs. The TGMs are identical 6 meter devices and the 8-1 TGM has been operated at a very high resolution of 6 meV at 60 eV. [3]

Beam Line 5, which consists of the LOCUST monochromator on a multiundulator beam line, is unique in that it has can cover a wide energy range of 20 eV to over 1000 eV. [4] The lower energy ranges have been fully commissioned, and when coupled to an angle resolved analyzer with multichannel detection, a total system resolution of 20 meV with count rates of 10^4 has been obtained on a Pt Fermi level. [5]

In addition to Beam Line 5, the energy range between several hundred eV to over one keV is covered by two SGM's (Stations 8-2 and 10-1) both of which have demonstrated resolutions of 10,000 at nitrogen 1s. Station 8-2 is on a bending magnet beam line and has the additional feature of being able to use an off-axis geometry to yield circularly polarized light. This has opened up a whole new area at SSRL for the study of magnetic materials. Station 10-1 is on a 32-pole wiggler giving very high fluxes at high resolution and has made possible soft x-ray fluorescence studies at SSRL.

Station 3-4 is a differentially pumped, white radiation station with a 3 keV high energy cut off on a bending magnet. [6] This is a very versatile station which has been used for x-ray lithography (both microlithography and micromachining), x-ray optics development, radiation damage and, most recently, x-ray microscopy and x-ray fluorescence detection of light impurity trace elements on surfaces including aluminum on silicon wafers. [7]

In 1993 a significant advance was made with the first operation of the soft x-ray JUMBO monochromator using YB_{66} (yttrium boride) crystals. These crystals open up the energy range encompassing the K-edges of magnesium, aluminum, and silicon. This development brought a large number of traditional x-ray users to the line, and plans for further enhancing Jumbo's use for these studies are underway.[8]

New developments include an elliptically polarizing undulator (EPU) to provide x-rays for the study of materials systems which exhibit magnetic circular dichroism. This undulator, presently under construction, will be installed in Beam Line 5. It will provide a greater degree of polarization and flux than the circularly polarized radiation available from bending magnets.[9]

Future Developments

Beam Line 9 - A New Facility for Structural Molecular Biology

Planning for a new multipole, high-intensity wiggler beam line on SPEAR to be completed at the end of 1995 is now underway. This beam line, which will be fully dedicated to structural molecular biology, will provide very high brightness radiation to three experimental stations configured for protein crystallography (white beam Laue and monochromatic), x-ray absorption spectroscopy, and x-ray small angle scattering/diffraction. User setup and workspace will be co-located with the beam line to give users an "integrated" environment for their structural molecular biology work.

The insertion device will be a be a 7.5 full period ($\lambda = 26$ cm) neodymium-iron-boron high-field wiggler (critical energy 11.37 keV). Most of this beam line will be located in an existing building at SSRL (building 120). A parallel expansion of the floor and mezzanine space around the building to accommodate user setup and work areas for the structural molecular biology experiments is underway.

The end station will provide a large hutch with significant working space for crystallographic experiments. Multiple-wavelength anomalous dispersion x-ray diffraction experiments will be carried out using monochromatic radiation from doubly focusing optics. By changing the optics, an intense white beam will be available for advanced time-resolved Laue diffraction experiments.

One side station will provide an intense focused beam from a triangular-shaped focusing crystal/mirror optics system for small angle scattering experiments. This dedicated system could be used for static as well as time-resolved x-ray scattering and diffraction studies of biological molecules.

A second side station would utilize a two-crystal monochromator combined with mirror harmonic rejection and/or focusing optics to provide very high intensity radiation to a station dedicated for x-ray absorption spectroscopy. The beam line optics would be optimized for studies in the 4-25 keV spectral region.

The SSRL building 120 in the area of Beam Line 9 is being expanded. This expansion adds about 8000 square feet of space, a part of which on the ground level will be occupied by the experimental stations on the beam line. In addition ample space will be available for providing SSRL staff and users with important supporting areas. Currently, five such areas are planned (but there is expansion space for a sixth should funding become available).

Construction of the beam line should be completed at the end of 1995, with first commissioning in the 1996 run. These stations will significantly enhance structural molecular biology research at SSRL by providing state of the art, dedicated facilities.

In parallel with the beam line design, fabrication and installation, an existing program to improve upon current instrumentation (particularly detector systems) is underway. These developments will add new capabilities when integrated with the stations on the new beam line, as well as providing for continuous upgrades to existing experimental stations.

Future Wiggler Lines - Facilities for Materials Processing and Environmental Sciences

SSRL has nine straight sections still available for the development of insertion device beam lines. In response to the growing interest in studying materials related to waste remediation and the use of synchrotron radiation for microcontamination and materials processing studies, SSRL is proposing to construct two dedicated wiggler lines. These lines, in an area behind the present Building 131, would be isolated from each other and the rest of the experimental floor to more easily enable the research which involves hazardous substances to be carried out.

Future Sources

A Linac Coherent Light Source Program

A collaboration of accelerator scientists from SLAC, UCLA, LLNL and LBL has been studying the use of the SLAC linac to drive short wavelength free electron lasers. [10] Free electron lasers (FELs) are presently operated at wavelengths from the centimeter region down to 240 nm, in the ultraviolet. Extending these devices to shorter wavelengths poses increasing difficulties due primarily to the lack of mirrors to form the optical cavity conventionally used in these FEL oscillators. It has recently become possible to consider another path to shorter wavelength, down to about 3 nm initially, and ultimately possibly down to 0.1 nm. This new class of FEL requires no mirrors. The approach used is called Self-Amplified Spontaneous-Emission (SASE), a process by which lasing action is achieved in a single pass of a high energy, high current, low emittance, electron bunch in a long undulator. An SASE device operates essentially as a high gain, single pass amplifier of spontaneous emission, rather than a low gain oscillator requiring an optical cavity. SASE sources operating at short wavelength are expected to provide orders of magnitude higher brightness, coherence, and peak power than any source now in operation or construction, opening up major new opportunities for basic and applied research.

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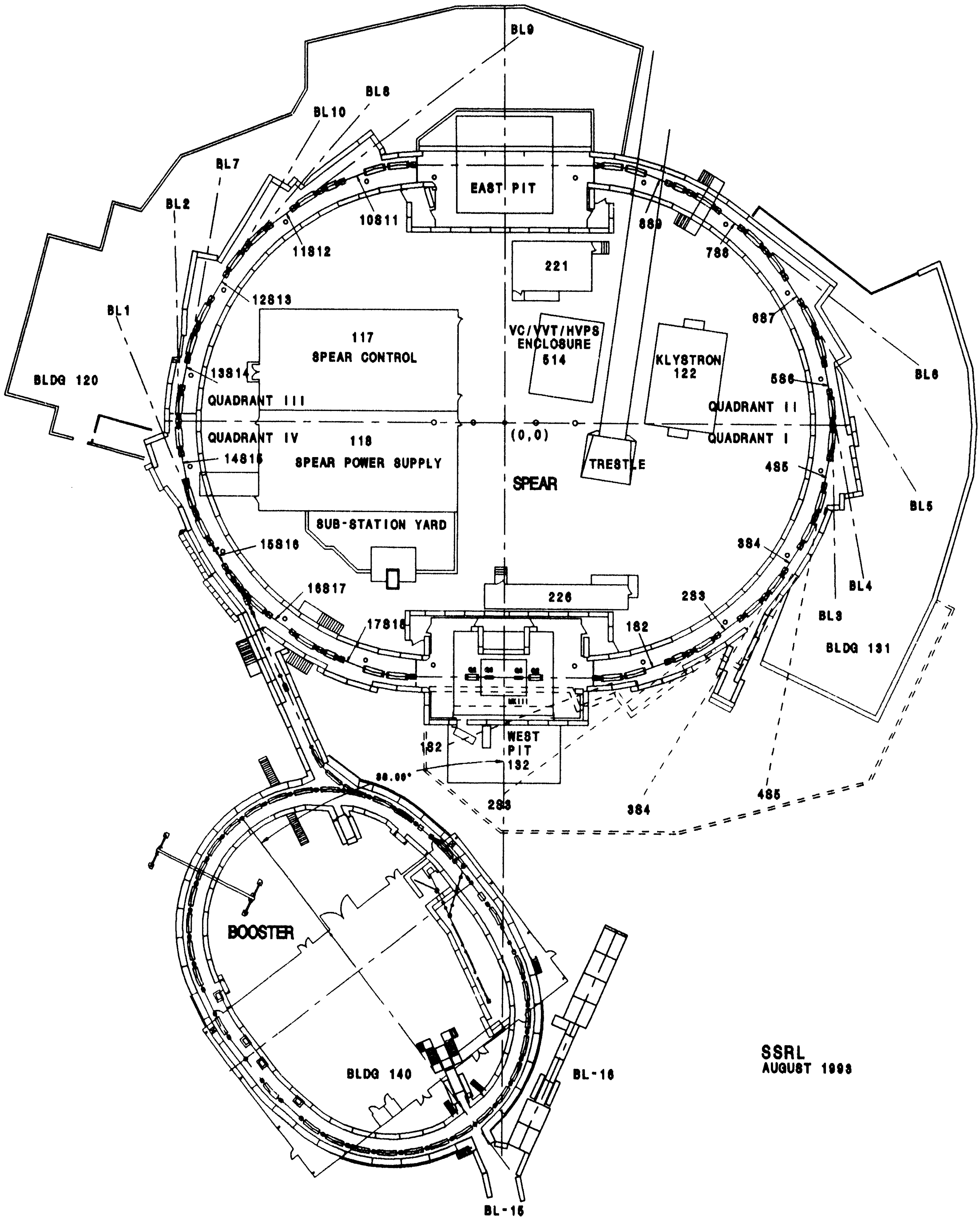

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QUADRANT II
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