Abstracts of papers presented at SRI '95

Status of the Advanced Photon Source at Argonne National Laboratory

David E. Moncton *Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois 60439* (Presented on 18 October 1995)

The Advanced Photon Source at Argonne National Laboratory is a third-generation light source optimized for production of high-brilliance undulator radiation in the hard x-ray portion of the spectrum. A user community representing all major centers of synchrotron research, including universities, industry, and federal laboratories, will utilize these x-ray beams for investigations across a diverse range of disciplines. All technical facilities and components required for operations have been completed and installed, and are well along in the commissioning process. Major design goals and Department of Energy milestones have been met or exceeded. Project funds have been maximized to construct a number of beamline components and user facilities over and above those called for in the original project scope. Research teams preparing experimental apparatus at the Advanced Photon Source have procured strong funding support.

Operational experience at the Advanced Light Source

Alan Jackson *Lawrence Berkeley National Laboratory, University of California, Berkeley, CA 94720* (Presented on 18 October 1995)

The Advanced Light Source (ALS) has been operational for users since October 1993 when white light from a bend magnet was delivered to the Center for X-Ray Optic's (CXRO) x-ray microprobe end station. Since then, the ALS has installed and commissioned three undulators and their beamlines (including monochromators and post-monochromator focusing optics), and eight bend-magnet beamlines, including one dedicated to machine diagnostics. Apart from one serious outage, when scheduled beam was not available to users for 17 days, the ALS has enjoyed remarkable operating statistics, with typically 95% of scheduled beam time delivered to the users. Beam quality has also been very good. With a vertical emittance measured at 0.06 nm-rad, the electron beam is kept stable to about one-tenth of its transverse dimensions, in the face of changing error fields in the insertion devices (as their main fields are varied), temperature variations, and floor vibration. The longitudinal motion of the beam, which leads to an increase in the electron beam energy spread and thence to a degradation of the undulator spectra, has recently been brought under control by the addition of an innovative feedback system. This paper focuses on those aspects of electron beam stability that we find most affect the ALS users: beam size and position, and energy spread.

The applications of a short-wavelength FEL

John Arthur *Stanford Synchrotron Radiation Laboratory, Stanford Linear Accelerator Center, Stanford, CA 94309* (Presented on 18 October 1995)

The third-generation synchrotron light sources today offer exciting new scientific capabilities due to the high brightness of their hard x-ray beams. Yet further dramatic increases in source brightness are becoming technically feasible, with the advent of free-electron lasers (FELs) operating in the hard x-ray region. The peak brightness of machines under consideration exceeds that of today's third-generation sources by more than ten orders of magnitude. In addition, an FEL would produce an x-ray beam with very high transverse coherence and subpicosecond pulse length. These characteristics should open up completely new areas of x-ray science, such as nonlinear x-ray optics and femtosecond time-domain spectroscopy. Some areas of current research, such as imaging and interferometry, could be extended to much shorter wavelengths and faster measurements. The intense beam could also be used to modify materials on a nanometer scale. Formidable technical problems in the areas of optics, sample preparation, and data collection will need to be solved before an FEL beam could be effectively utilized. Research in these areas is now beginning to be pursued in the U.S., Germany, and Japan.

Innovations in the operation of storage rings

R. O. Hettel *Stanford Synchrotron Radiation Laboratory, Stanford, CA 94309* (Presented on 18 October 1995)

Developments in stored beam measurement, control, and modeling methods at synchrotron radiation laboratories around the world are helping to produce brighter, more stable beams having improved temporal and spectral properties. Beam-based storage ring lattice identification and model calibration, beam dynamics monitoring and stabilizing systems, and improved operational procedures facilitated by advanced control systems are benefitting new and older facilities alike. An overview of these innovations and their impact on photon beam quality is presented.

Magnet system of the SPring-8 booster synchrotron

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The construction of the SPring-8 booster synchrotron was started in 1993. The synchrotron has a two-fold symmetric lattice composed of 40 FODO cells. There are 30 normal cells and 2 straight sections, and it is composed of 64 bending magnets. The integral values of the magnetic field of the bending magnets were measured, and adequate results were obtained. The power supply of the bending magnets, which must be operated following a trapezoidal excitation-curve of the output current, is being constructed and tested now. This report presents the results of the integral values of the magnetic field of the bending magnets and the excitation-curve measurement of the power supply.

Plans for conversion of SURF II to SURF III

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The Synchrotron Ultraviolet Radiation Facility (SURF II) at the National Institute of Standards and Technology, Gaithersburg, MD, USA, has served as a primary radiometric standard in the vacuum

ultraviolet region since its conversion from a synchrotron to an electron storage ring in 1974. The magnet iron, however, dates back to an original betatron design of the late 1940s. The advent of both modern materials and methods of finite element analysis have made possible the design of magnets offering far greater dc performance than the existing SURF system. In this paper we discuss the general design and plans to convert SURF II to SURF III, which will offer reduced radiometric uncertainty, an increase in energy from 300 MeV to 385 MeV, a modernized control system, and two new beamlines, which are not presently possible. Anticipated new beamline activities include a substantial new effort devoted to radiometric improvements from IR to far UV and development of stations for microspectoscopy and electroreflectance.

Infrared radiation from bending magnet edges in an electron storage ring

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The infrared radiation emitted by electrons entering or exiting a storage ring bending magnet, which is termed ''edge'' radiation, is computed. The numerical results are in agreement with experimental observations at a wavelength of 1 μm. A comparison is made with the infrared synchrotron radiation emitted from the central region of a bending magnet for wavelengths of 1 μm–1000 μm. The flux of the edge radiation is lower than that of the synchrotron radiation for the shorter wavelengths studied, and greater for the longer wavelengths. However, the brightness of the edge radiation is higher for all of the wavelengths studied. This suggests that edge radiation may be a promising infrared radiation source.

Elliptical multipole wiggler for the production of variably polarized radiation

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A new insertion device has been designed, manufactured, and tested as a result of a collaboration between the Advanced Photon Source, the Budker Institute of Nuclear Physics, and the National Synchrotron Light Source. The device—an elliptical multipole wiggler (EMW)—is a source of variably polarized x-rays. It has a period of 16 cm and consists of two magnetic structures. The hybrid magnet structure produces a vertical wiggler field with a peak value of 8 kG. The horizontal wiggler field (1 kG) is generated by electric coils capable of operating with a switching frequency up to 100 Hz. After fabrication, the EMW was measured and magnetically tuned. When installed on the NSLS X-ray Ring, the EMW produces variably polarized radiation in the 1–10 keV energy range.

Orbit compensation for the time varying elliptically polarized wiggler

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In December 1994, an elliptically polarized wiggler was installed in the X13 straight section of the NSLS X-ray Ring. This device generates circularly polarized photons in the energy range of 0.1–10 keV with AC modulation of polarization helicity. The vertical magnetic field is produced by a hybrid permanent magnet structure, and the horizontal magnetic field is generated by an electromagnet capable of operating with a switching frequency of up to 100 Hz. The elliptically polarized wiggler was commissioned during spring 1995 at an operating frequency of 2 Hz. Here, we discuss the compensation of the residual-orbit motion-utilizing trim coils at the wiggler ends and the high precision orbit measurement system of the X-Ray ring.

Experience with small-gap undulators

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Small-gap undulators offer enhanced performance as synchrotron radiation sources, by providing extended tuning range and the possibility of higher photon energies via short-period, small-gap devices. Challenges associated with the operation of small-gap undulators arise from their requirement for small beam apertures and the resulting possibility of lifetime degradation, beam instabilities, and radiation hazards. To investigate these fundamental limitations, we have constructed an R&D small-gap undulator for the X13 straight section of the NSLS 2.584 GeV X-ray Ring and have tested it during studies shifts and normal user shifts during the last year. This device, the NSLS prototype small-gap undulator (PSGU), consists of a variable-aperture vacuum chamber and a 16-mm-period pure-permanent-magnet undulator, both mounted to a common elevator base stage. The design output spectrum of 2.5 keV in the fundamental (and 7.5 keV in the third harmonic) was obtained with a magnet gap of 5.6 mm and an electron beam aperture of 2.5 mm. The partial lifetime contribution for these parameters was observed to be about 40 hr. Details of the synchrotron radiation output spectrum, lifetime dependence on aperture, and bremsstrahlung radiation production will be presented.

Status of the ESRF insertion devices

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The cumulated length of insertion devices in operation at the ESRF reaches 44 m, segmented in 29 devices serving 20 beamlines. The majority are conventional vertical sinusoidal field devices made of permanent magnet. Exotic insertion devices have been installed, such as helical undulators with variable polarization, asymmetric wigglers, a variable gap chamber short undulator and a 5 T superconducting wiggler. With the new low emittance lattice, a single undulator segment generates hard x-rays with a record brilliance of $2x10^{19}$ phot./s/.1%/mm^2/mr^2. All devices have been produced in-house, and the methods of field correction based on shimming are summarized. Recent developments concerning the design of undulator/wiggler terminations are described, which minimize or eliminate the need for electromagnet correctors on hybrid wigglers or allow the implementation of variable length segmented undulators.

Performance of Advanced Photon Source insertion devices at high photon energies (50–300 keV)

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Since high-energy photons (>50 keV) are well suited for certain types of x-ray scattering experiments, we present calculated results for the Advanced Photon Source (APS) Undulator A and APS Wiggler A at high energies. The undulator calculations include the effect of magnetic field errors, which is to smear the high-order spectral harmonics. At their anticipated initial minimum gap settings, Undulator A should perform better than Wiggler A from the point of view of most high energy experiments up to at least ~280 keV. A comparison of APS insertion devices to high energy insertion devices in other synchrotron radiation laboratories is also provided.

Design and performance of a 2T permanent magnet wiggler for the Stanford Synchrotron Radiation Laboratory

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The Beamline 9 Wiggler was designed by Intermagnetics to produce a 16 milliradian fan of high energy x-rays into three experimental stations. The device has a 26 cm period and contains 7.5 full-strength periods. The minimum air gap is 2.1 cm. At minimum gap, a peak field of 1.9 Tesla and a half-period integrated field strength of ⩾16.646 T-cm were specified by the Stanford Synchrotron Radiation Laboratory (SSRL). A combination of analytical, PANDIRA, and scale models were used to develop a novel ''compact pole'' magnetic design. This design achieved 2.04 T peak field while maintaining a minimum of 17.816 T-cm half-period integrated field strength. Magnetic performance of the device was confirmed through the use of an Intermagnetics-designed Hall Probe scanning system as well as by long and short coil measurements.

Advances in undulator technology at STI Optronics

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Undulator and wigglers are an essential basis for synchrotron radiation and free-electron laser systems. Wiggler and undulator design concepts for producing higher magnetic field strength with improved field quality are reviewed. Shim tuning methods have permitted magnetic field tolerances, including pole-to-pole field uniformity, trajectory straightness, and higher order moments, to be controlled to low levels as needed for various applications. A key figure of merit is the optical phase error, which determines the coherence of the light generated in the device. Coherence is a strict requirement for maintaining spectral intensity in synchrotron radiation sources with low emittance and maximizing gain in free-electron lasers.

Central field design methods for hybrid insertion devices

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The design of the insertion devices built and tested by STI Optronics for the Advanced Photon Source (APS) have used initial Halbach scoping followed by 2D and 3D finite element analysis (FEA). We review our design methods, which ensure the fabricated devices achieve the requested on-axis field strength, minimize pole saturation and demagnetizing fields, and reduce harmonic content, transverse roll-off, and flux leakages to desired levels. Recent enhancements include additional assessment of the effects of excessively strong magnets, magnet inhomogeneity, transverse pole saturations, part placement sensitivity, and refinements in the material databases used by the FEA.

Multipole and phase tuning methods for insertion devices

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Multipole and phase tuning of insertion devices is important for maintaining beam dynamics and reaching the high brightness goals of the Advanced Photon Source. Several general approaches are described: mechanical adjustments, end-pole shaping, and magnetic shimming. Off-axis Hall probe measurements after assembly guide magnet exchanges and local mechanical adjustments. A recent development has been the use of potential theory applied to end-pole shaping. The wide gap tuning range of the APS devices requires careful matching of device errors and correct gap dependencies in the gap/period range of 0.18 to 0.6. Shims are especially sensitive at small gaps. We describe signatures, gap dependencies, algorithms, modeling, and experimental results for these techniques.

End-field design and tuning methods for insertion devices

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The magnetic field distribution, gap-dependent steering, and integrated magnetic multipole moments of insertion devices installed in synchrotron radiation sources have stringent requirements for yielding high brightness without adversely perturbing the electron orbit. Correct termination of the ends of the device yields a large number of full-field poles and helps achieve gap-independent steering. End-field tuning methods used for the Advanced Photon Source insertion devices are reviewed. Techniques include magnet strength reduction, reduced height poles, magnetic shims, and pole shaping. Measurements show that two-imensional finite element analysis is a useful tool for predicting general field shape and trajectories. However, experimental entrance steering of different devices with identical end configurations shows variance, necessitating empirical fine tuning of each device.

Design of the vacuum system for the elliptical multipole wiggler at the Advanced Photon Source

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A vacuum system for the Advanced Photon Source elliptical multipole wiggler (EMW) that will operate at a pressure of 10^{-9} Torr with a storage ring current of 100 mA at 7.0 GeV has been designed and is being fabricated. The major part of the system is a stainless

steel chamber with a 66.6 mm by 19.6 mm rectangular cross section. The length of the vacuum chamber is 3100 mm, and the wall thickness is 1.2 mm. Two versions of the vacuum chamber will be produced: with and without distributed nonevaporable getter (NEG) pumping. The version with NEG pumping will have slides on the top and bottom walls to accommodate sintered plates available from SAES. To activate these plates, the entire vacuum chamber will be baked from the outside up to a temperature of 350° C–450 °C. Provision for the baking is included in the design of the vacuum system, its support, and in the EMW itself. The complexity introduced into the design by the need for external activation of the NEG plates is eliminated in the design of the second version of the chamber. In this chamber, a sufficiently low outgassing rate may be achieved by extensive surface cleaning and baking in a vacuum furnace (10^{-6} Torr) up to a temperature of 950 ° C as has been achieved at the ESRF. Both versions are being pursued in parallel.

Fabrication of mm-wave undulator cavities using deep x-ray lithography

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The possibility of fabricating mm-wave radio frequency cavities (100–300 GHz) using deep x-ray lithography (DXRL) is being investigated. The fabrication process includes manufacture of precision x-ray masks, exposure of positive resist by x-ray through the mask, resist development, and electroforming of the final microstructure. Highly precise, two-dimensional features can be machined onto wafers using DXRL. Major challenges are: fabrication of the wafers into three-dimensional rf structures; alignment and overlay accuracy of structures; adhesion of the PMMA on the copper substrate; and selection of a developer to obtain high resolution. Rectangular cavity geometry is best suited to this fabrication technique. A 30- or 84-cell 108-GHz mm-wave structure can serve as an electromagnetic undulator. A mm-wave undulator, which will be discussed later, may have special features compared to the conventional undulator. First harmonic undulator radiation at 5.2 keV would be possible using the Advanced Photon Source (APS) linac system, which provides a low-emittance electron beam by using an rf thermionic gun with an energy as high as 750 MeV. More detailed rf simulation, heat extraction analysis, beam dynamics using a mm-wave structure, and measurements on 10x larger scale models can be found in these proceedings [Y.W. Kang *et al.*, ''Design and Construction of Planar mm-wave Accelerating Cavity Structures'']

Design and construction of planar mm-wave accelerating cavity structures

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Feasibility studies on planar millimeter-wave cavity structures have been made. The structures could be used for linear accelerators, free-electron lasers, mm-wave amplifiers, or mm-wave undulators. The cavity structures are intended to be manufactured by using DXL (deep x-ray lithography) microfabrication technology. The frequency of operation can be about 30 GHz to 300 GHz. For most applications, a complete structure consists of two identical planar half structures put together face-to-face. Construction and properties of the constant gradient structures that have been investigated so far will be discussed. These cavity structures have been designed for 120 GHz $2\pi/3$-mode operation.

APS undulator radiation—first results

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The first undulator radiation has been extracted from the Advanced Photon Source (APS). The results from the characterization of this radiation are very satisfactory. With the undulator set at a gap of 15.8 mm ($K=1.61$), harmonics as high as the 17th were observed using a crystal spectrometer. The angular distribution of the third-harmonic radiation was measured, and the source was imaged using a zone plate to determine the particle beam emittance. The horizontal beam emittance was found to be 6.9 ± 1.0 nm-rad, and the vertical emittance coupling was found to be less than 3%. The absolute spectral flux was measured over a wide range of photon energies, and it agrees remarkably well with the theoretical calculations based on the measured undulator magnetic field profile and the measured beam emittance. These results indicate that both the emittance of the electron beam and the undulator magnetic field quality exceed the original specifications.

Spatial imaging of monochromatic hard x-rays from an APS undulator by the Kohzu double-crystal monochromator

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The spatial distribution of monochromatic x-rays produced by an APS undulator was imaged on a fluorescent screen and recorded with a video camera while commissioning the Kohzu double-crystal monochromator (DCM). Two sets of images were recorded: Case 1 in which the spectral output of the undulator is fixed (constant magnetic gap) and the monochromator is scanned in energy, and Case 2 in which the monochromator energy is held fixed and the spectral output of the undulator is varied by changing the magnetic gap of the insertion device. Because of the performance of the Kohzu monochromator, the mechanical conditions required to maintain the twice-diffracted beam could be preserved as the DCM was scanned in energy, allowing the evolution as a function of energy. The images are compared with the calculated spatial distributions of monochromatic undulator radiation.

Cryogenically cooled monochromators for the Advanced Photon Source

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The use of cryogenically cooled monochromators looks to be a very promising possibility for the Advanced Photon Source. This position has recently been bolstered by several experiments performed on beamlines at the ESRF and CHESS. At the ESRF, several crystal geometries have been tested that were designed for high power densities ($>$150 W/mm^2) and moderate total absorbed powers ($<$200 W). These geometries have proven to be very successful at handling these power parameters with measured strains on the arc-second level. The experiments performed at CHESS were focused on high total power ($>$1000 W) but moderate power densities. As with the previously mentioned experiments, the crystals designed for this application performed superbly with no measurable broadening of the rocking curves on the arc-second level. These experiments will be summarized and, based on these results, the performance of cryogenic monochromators for the APS will be assessed.

Optics for high energy x-ray scattering applications Thomas Tschentscher *ESRF, B.P.220, F-38043 Grenoble-Cedex, France* (Presented on 20 October 1995)

High energy photons in the range from 80 to 500 keV are a relatively new tool, which is provided with sufficient fluxes only by the latest generation of synchrotron sources. Due to the high energies and, respectively, very short wavelengths, new arrangements for monochromators or mirrors have to be investigated in addition to standard monochromator concepts. An overview of possible monochromator setups is given and the need for experiments to be performed at these energies is evaluated. Low absorption enables the use of rather thick absorbers in order to reduce the heat load problem, which is due to the high power synchrotron beam. Even monochromator crystals become semitransparent, thus giving the possibility of operating more than one experimental station using the same synchrotron beam. Focusing techniques may be applied, and monochromators with an increased bandwidth are of interest for providing sufficient monochromatic flux. The optical concept of the High Energy beamline ID15 at the ESRF is presented, where two different insertion devices can be used alternatingly. Monochromatic beam in the range from 30 to 80 keV is provided by the use of bent cooled Si monochromators and the results of the performance tests are shown.

Design and analysis of a high heat load pin-post monochromator crystal with an integral water manifold
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Conventional minichannel water cooling geometry will not perform satisfactorily for x-radiation from a wiggler source at the Advanced Photon Source. For closed-gap wiggler operation, cryogenic silicon appears to be the only option for crystals in Bragg-Bragg geometry. For operation of the wiggler at more modest critical energies ($<$17 keV), the first crystal can be cooled by a pin-post cooling scheme, using water at room temperature as a coolant. In order to limit the water consumption to 4 gpm and hence the risk of introducing vibrations to the crystal, the intensely cooled area of the crystal was matched to the footprint of the beam, leaving a less cooled area of the crystal subject to survival in a missteered beam but not to perform as a monochromator. The manifold design avoids large areas of high water pressure that would bow the crystal. We present here the design of a pin-post monochromator consisting of a four-layer silicon manifold system and an integrally bonded 39% nickel-iron alloy base plate. A transparent prototype of the design will be exhibited. Fabrication techniques and design advantages will be discussed.

A cryogenic monochromator for third-generation synchrotrons
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A double-crystal monochromator has been developed based upon the cooling of a pair of silicon (111) crystals using liquid nitrogen. This monochromator features Bragg angle accuracy and a resolution of 0.36 arc seconds and is also compatible with sagittal focusing of the second crystal. The design of this monochromator is described, and performance data are presented.

A diamond double-crystal transmission monochromator for the TROIKA II station at ESRF
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The performance of a diamond double-crystal monochromator for the TROIKA II station at the ESRF was studied. Two (111) oriented diamond crystals for Bragg geometry (120 mm and 500 mm thick) were combined in a nondispersive horizontal scattering geometry and characterized in the white Troika undulator beam. The observed rocking curves were slightly broadened due to nonuniform defect distributions present in the crystals. No heat-load-induced broadening was found. The measured reflectivities compared well to the calculated values, and it was shown that a double-crystal Bragg monochromator can replace a single-reflection Laue monochromator without loss in flux.

Liquid-metal-cooled curved-crystal monochromator for Advanced Photon Source bending-magnet beamline 1-BM
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We describe a horizontally focusing curved-crystal monochromator that invokes a 4-point bending scheme and a liquid-metal cooling bath. The device has been designed for dispersive diffraction and spectroscopy in the 5–20 keV range, with a predicted focal spot size of $\leqslant 100$ μm. To minimize thermal distortions and thermal equilibration time, the $355\times32\times0.8$ mm crystal will be nearly half submerged in a bath of Ga-In-Sn-Zn alloy. The liquid metal thermally couples the crystal to the water-cooled Cu frame, while permitting the required crystal bending. Calculated thermal profiles and anticipated focusing properties are discussed.

Further tests on liquid-nitrogen-cooled, thin silicon-crystal monochromators using a focused wiggler synchrotron beam
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A newly designed, cryogenically cooled, thin Si crystal monochromator was tested at the European Synchrotron Radiation Facility (ESRF) beamline BL3. It exhibited less than 1 arcsec of thermal strain up to a maximum incident power of 186 W and average power density of 521 W/mm^2. Data were collected for the thin (0.7 mm) portion of the crystal and for the thick ($>$25 mm) part. Rocking curves were measured as a function of incident power. With a low power beam, the Si(333) rocking curve at 30 keV for the thin and thick sections was $<$1 arcsec FWHM at room temperature. The rocking curve of the thin section increased to 2.0 arcsec when cooled to 78 K, while the thick part was unaffected by the reduction in temperature. The rocking curve of the thin section broadened to 2.5 arcsec FWHM and that of the thick section broadened to 1.7 arcsec at the highest incident power. The proven range of performance for this monochromator has been extended to the power density, but not the absorbed power, expected for the Advanced Photon Source (APS) undulator A in closed-gap operation (first harmonic at 3.27 keV) at a storage-ring current of 300 mA.

Performance of cryogenically cooled, high-heat-load silicon crystal monochromators with porous media augmentation
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The performance of two Si crystal x-ray monochromators internally cooled with liquid nitrogen was tested on the F2-wiggler beamline at the Cornell High Energy Synchrotron Source (CHESS). Both crystals were (111)-oriented blocks of rectangular cross section having identical dimensions. Seven 6.4-mm-diameter coolant channels were drilled through the crystals along the beam direction. In one of the crystals, porous Cu mesh inserts were bonded into the channels to enhance the heat transfer. The channels of the second crystal were left as drilled. Symmetric, double-crystal rocking curves were recorded simultaneously for both the first and third order reflections at 8 and 24 keV. The power load on the cooled crystal was adjusted by varying the horizontal beam size using slits. The measured Si(333) rocking curve of the unenhanced crystal at 24 keV at low power was 1.9 arcsec FWHM. The theoretical width is 0.63 arcsec. The difference is due to residual fabrication and mounting strain. For a maximum incident power of 601 W and an average power density of about 10 W/mm^2, the rocking curve was 2.7 arcsec. The rocking curve width for the enhanced crystal at low power was 2.4 arcsec. At a maximum incident power of 1803 W and an average power density of about 19 W/mm^2, the rocking curve width was 2.2 arcsec FWHM. The use of porous mesh augmentation is a simple, but very effective, means to improve the performance of cryogenically cooled Si monochromators exposed to high power x-ray beams.

Performance analysis of a novel monochromator design for the APS SRI-CAT beamline 2-ID-E
Zhibi Wang, Wenbing Yun, and Tuncer Kuzay *Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439* (Presented on 19 October 1995)

Third-generation synchrotron x-ray facilities, such as the Advanced Photon Source, produce x-ray beams that generate a very high heat flux in a very small area. In order to preserve the brilliance of the source, optical components have to be designed to undergo very small thermal deformation (or a change of slope of a flat surface). When an optical component is subjected to a heat load, there will be thermal deformation caused by a temperature increase from the initial state. For a plate-like structure, the temperature difference over the thickness causes bending, and the average temperature increment causes axial deformation. For an optical element, the slope change due to bending is the main reason for the degradation of the performance of the optical component. The change of slope should be limited to a few microradians. There are many ways to control the thermal deformation, such as cryogenic cooling, inclined geometry, liquid-metal cooling, pin-posts or microchannels, using a high-heat-conductivity material, such as diamond, etc. In an accompanying conference paper, an adaptive design technique has been proposed to make use of a novel self-adapted smart structure. Its performance is essentially independent of the heat-load intensity. When such a device is exposed to a heat load, the flat surface remains flat in the area of interest. Therefore this technique can potentially be used to achieve a high precision optical component. Application of the proposed design technique to the monochromator for the SRI-CAT Sector 2 insertion device beamline (Sector 2-ID-E) is explained, and initial analytical results are presented on its performance.

Replica grating radiation damage in a normal incidence monochromator
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Experience with the Synchrotron Radiation Center 4 meter normal incidence monochromator has revealed short operational life for the high energy gratings. Within periods as short as 6 months, the resolution of the gratings degraded sufficiently to limit the resolution to values expected with 80 micron slits. This decrease in resolution occurs without any noticeable changes in the efficiency or throughput of the grating. The resolution degradation has been shown to have been caused by light between 100 and 200 eV, which was transmitted through the gold layer of the replica grating and caused shrinkage of the epoxy. This resulted in distortion of the surface. The problem was solved by ordering a special replica grating with a double layer of gold. Calculations indicate that a thicker gold layer should decrease the flux penetrating the epoxy layer by a factor of ten slowing down the deterioration of the grating figure. A grating with a double thickness gold layer has been operating in the monochromator for more than one year with no noticeable decrease in the resolution.

A new double-crystal monochromator for UHV operation in the low to medium photon energy range
W.P. Mason, G.R. Emmel, F. Feyzi, D.J. Holly, F.H. Middleton, and A.J. Pagac *University of Wisconsin-Madison, Physical Sciences Laboratory, Stoughton, WI 53589* (Presented on 19 October 1995)

The University of Wisconsin-Madison Physical Sciences Laboratory (PSL) has developed a new concept patented double-crystal monochromator for instruments operating in the low to medium photon energy range. Presently PSL is engaged in a collaborative project with the Pohang Light Source in South Korea to provide the internal mechanism for such a DCM; Pohang will supply the vacuum chamber and scan drive. The concept utilizes a straight arm linear rotating link called the ''broomstick'' that is a cotangent generator. Coupled to the broomstick is a pair of unique half angle mechanisms that rotate the crystals at half the angle of the broomstick while maintaining crystal parallelism during the scan rotation. An external linear drive to one crystal through a bellows assembly provides the only required input for operation of the monochromator other than crystal angular adjustments by manual or piezoelectric means. The instrument is capable of operating at Bragg angles from 8° to 80°. This results in an energy range of 2 keV to 14.2 keV for Si(111) crystals. The instrument is also capable of UHV operation in the $1.0E^{-10}$ Torr range.

A new compact double crystal monochromator for high energy synchrotron radiation and ultrahigh vacuum operation
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The UW-Madison Physical Sciences Laboratory proposed a unique double crystal monochromator to the Advanced Photon Source and UNI-CAT that has resulted in two development projects for the instrument. These two very similar designs are capable of accepting inclined geometry, other high heat load optics, and sagittal focusing crystals by provisions of ample space for such optical elements. The monochromator is a compact instrument. It has a single rotational stage that does not require a track system to access the crystals yet will fit in the confined back space at APS by having only 300 mm distance between the beam centerline and back of the instrument. The frame footprint is only 0.74 m x 0.84 m. The instrument is truly UHV rated for vacuum in the $1.0E^{-10}$ Torr range by virtue of its unique internal mechanisms for linear positioning and rotational adjustment of crystals. The design may be modified for operation at low energy synchrotron radiation in the 0.8 to 4.0 keV range requiring higher Bragg angles.

Mechanical design of a plane grating monochromator for the new undulator at Aladdin
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A nearly stigmatic plane grating monochromator under construction for the new undulator beamline at Aladdin will provide a resolving power >10000 as it scans from 8 to 240 eV with a single grating. Scanning requires the precise, simultaneous movements of both a plane mirror and a plane grating in close proximity to one another inside a UHV chamber. The mirror, which absorbs up to 16.5 watts, is internally water cooled to minimize thermally induced slope errors. The radiatively cooled grating absorbs less than a watt. Careful examination of the focusing requirements revealed that the monochromator could be scanned either in the conventional mode of rotating-translating the mirror and rotating the grating or in a modified mode of rotating the mirror and rotating-translating the grating. The latter mode was chosen for simplicity of design. The mirror and grating rotate nearly 30 and 40 degrees, respectively, with subarcsec resolution. Both utilize a stepping-motor lead-screw piezoelectric actuator scan drive that is controlled with a feedback loop using a laser interferometer to measure the actual rotation of the optics. The grating mechanism translates nearly 200 mm along a granite surface plate with a positional accuracy and vertical stability of a few micrometers.

Design and testing of a new, simple continuous bent sagittally focusing monochromator
Stefan Kycia, Kazuhiko Inoue, and Qun Shen *CHESS, Cornell University, Wilson Laboratory, Ithaca, NY 14853-8001* (Presented on 19 October 1995)

A continuous bent sagittally focusing monochromator has been designed and built. The monochromator is compatible with the present single-point bender apparatus designed for polygonal (ribbed) triangular sagittally focusing monochromators. This monochromator implements a new design concept taking advantage of a tapered rectangular wafer to allow for sagittal bending while simultaneously minimizing anticlastic bending. The monochromator was optimized to operate at x-ray energies in the range of 5 to 25 keV. The design was derived from finite element analysis using ANSYS. The monochromator performance was tested by means of an apparatus implementing an x-ray tube source and a double-crystal configuration. This method yields precise contour maps of the entire monochromator surface. Details of the monochromator design, test apparatus, and corresponding results will be presented.

Improved monochromator design for high heat load beamlines at CHESS K.W. Smolenski, R. Pahl, P. Doing, C. Conolly, B. Clark, J. Ehen, and Q. Shen *CHESS, Cornell University, Wilson Laboratory, Ithaca, NY 14853* (Presented on 19 October 1995)

The use of water-cooling channels in silicon x-ray monochromators for the Cornell High Energy Synchrotron Source (CHESS) high power wiggler beamlines has been studied by finite element analysis. The efficiency from channels of different dimensions, ranging from 25 mm to 2 mm width and 5 mm depth, has been calculated. The new crystals are designed to replace the indirect cooled monochromators currently used at CHESS wiggler stations. At typical operation parameters of 150 mA electron current at 5.3 GeV and a gap of 40 mm, the 24-pole wiggler at CHESS provides an x-ray beam with a total power of 2.7 kW at the monochromator. Procedures have been developed for fabrication of internally cooled crystals using a silver-glass dye attach paste. Tests of a new crystal with a conventional x-ray source revealed very small amounts of residual strain. Experiments with synchrotron radiation are scheduled in the near future.

FEA analysis of diamond as IMCA's monochromator crystal
John Chrzas, Sorinel Cimpoes, and Ivan Neschev Ivanov *CSRRI, Illinois Institute of Technology, 3301 S. Dearborn Street, Chicago, IL 60616* (Presented on 19 October 1995)

A great deal of effort has been make in recent years in the field of undulator high heat load optics, and currently there are several tractable options [Rev. Sci. Instrum. **69**, 2792 (1994); Nucl. Instrum. Methods A **266**, 517 (1988); Nucl. Instrum. Methods A **239**, 555 (1993)]. Diamond crystals offer some attractive options–water as the coolant, the use of established monochromator mechanisms,

simpler monochromator design as compared to the use of liquid nitrogen or gallium. The use of diamond crystals as the optical elements in a double-crystal monochromator for the IMCA-CAT and MR-CAT ID beamlines has been studied. A first crystal mounting scheme using an indium-gallium eutectic as the heat transfer medium developed in collaboration with DND-CAT and M. Hart will be presented. A FEA analysis of the IMCA-CAT ID beamline arrangement using the APS undulator A as the radiaiton source will be presented.

Asymmetric 2-bounce monochromator for quasi-fixed offset
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In many monochromatic x-ray applications, it is important to maintain a constant direction of the monochromatized beam, preferably parallel to the direction of the original beam. For the most exacting applications, independent-crystal two-bounce monochromators can be used. These however, are costly and cumbersome. Therefore, in less demanding situations or when space is at premium, two-bounce channel-cut monochromators are commonly used. Unfortunately, while the direction of the beam emerging from a channel-cut monochromator is fixed, the beam offset varies with the angle of incidence, i.e., with the energy of the monochromatic beam. This complicates experiments in which it is important to maintain the beam on a fixed spot of the sample. We show, however, that the variation of beam offset in channel-cut monochromators can be greatly reduced by introducing a small amount of asymmetry into the cut. The exact amount of asymmetry (typically a few degrees) depends, of course, on the crystal and the energy range. We will present a full mathematical analysis and a design of a working monochromator based on this scheme.

Double-crystal monochromator as the first optical element in BESSRC-CAT beamlines Mark A. Beno *Materials Science Division, Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, IL 60439* Mohan Ramanathan *XFD/APS, Bldg. 400, Argonne National Laboratory, 9700 S. Cass Ave, Argonne, IL 60439* (Presented on 19 October 1995)

The first optical element in the BESSRC-CAT beamlines at the Advanced Photon Source will be a monochromator, so that a standard design for this critical component is advantageous. The monochromator we have designed is a double-crystal, fixed-exit scheme with a constant offset designed for UHV operation, thereby allowing windowless operation of the beamlines. The crystals are mounted on a turntable with the first crystal at the center of rotation. A mechanical linkage is used to correctly position the second crystal and maintain a constant offset. The main drive for the rotary motion is provided by a vacuum-compatible Huber goniometer isolated from the main vacuum chamber. Rotary motion of the primary monochromator stage is accomplished by using two adjacent vacuum chambers connected only by the small annular opening around a hollow stainless steel shaft, which connects the Huber goniometer to the turntable on which the crystals are mounted. The design of the monochromator is such that it can accommodate both water and liquid nitrogen cooling for the crystal optics. The basic design for the monochromator linkage mechanism will be presented along with details of the monochromator chamber. The results of initial optical tests of the monochromator system using tilt sensors and a precision autocollimator will also be given.

Why cryogenically cooled, thin crystals handle extremely high power densities
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Recently, a new type of cryogenically cooled high heat load monochromator was proposed [Knapp *et al.*, Rev. Sci. Instrum. **65**, 2792 (1994)] and developed at Argonne National Laboratory [Knapp *et al.*, Rev. Sci. Instrum. **66**, 2138 (1995)] and tested [Rogers *et al.*, Rev. Sci. Instrum. **66**, 3494 (1995)] at the European Synchrotron Radiation Facility (ESRF). These tests showed that powers of 153 W and power densities of 450 W/mm^2 cause only negligible strain. These powers and power densities are larger than will be absorbed by the first crystal on an undulator beamline at the Advanced Photon Source (APS). In our earlier work, we suggested that the crystal might show strain at much lower values of the powers and power densities. We now can explain the ESRF results in terms of the unique role the negative thermal expansion coefficient of Si plays in minimizing strain.

IMCA-CAT BM first monochromator crystal optimization
Ivan Neschev Ivanov, Sorinel Cimpoes, and John Chrzas *CSRRI, Illinois Institute of Technology, 3301 S. Dearborn Street, Chicago, Il 60616* (Presented on 19 October 1995)

The high heat load at the surfaces of the first x-ray optical elements at the APS requires special measures to be taken to more completely utilize the beam. A conceptually new design for such an element, proposed, realized, and tested by M. Hart and conveniently called ''matchbox,'' is to be implemented at the IMCA-CAT BM beamline as the first monochromator crystal. The requirements of the IMCA-CAT companies for the BM beamline dictate that an optimization of the design is made for a given x-ray energy range $E=13$ keV ± 1 keV. A modification of the original design to improve the vacuum compatibility of the device was made in collaboration with M. Hart. A FEA optimization of the geometry is made using the ALGOR and ABAQUS programs. Determination of the resulting slopes and the useful crystal surface after the best compensation of the thermal distortions are also made. The surface profile obtained by the FEA study was used to perform a ray-tracing analysis of the IMCA-CAT BM beamline. The results of the ray-tracing study will be presented.

Phase space analysis of a 4-bounce high resolution monochromator M. Popovici *Missouri University Research Reactor, Research Park, Columbia, MO 65211* (Presented on 19 October 1995)

A high resolution 4-bounce monochromator with nested pairs of channel-cut Si (422) and (10 6 4) crystals in $(+n,+m,-m,-n)$ configuration was recently implemented for signal-to-background enhancement in coherent nuclear resonant scattering measurements. In this paper, it is analyzed by using methods that have been developed for neutron optics. The overall throughput can be improved by bending the outer (422) pair. The bending relaxes the usual requirements on the reflection asymmetry of flat crystals, so that both (422) crystals can be set in beam condensation geometry. This results in large gains in flux at moderate gains in total beam intensity.

Wide-bandpass "multilayer" monochromator for small angle scattering/diffraction studies on biological systems

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We have utilized a ''multilayer'' monochromator (a pair of layered synthetic microstructures) in small-angle x-ray scattering/diffraction studies of biological materials. Many biological applications of the SAXS/D technique, in particular time-resolved studies, are often limited by the flux available to experiments. The wider energy bandpass of the multilayer monochromator provides a higher beam flux by a factor of 10 or more, compared with that of the Si(111) double-crystal monochromator. At the SSRL BL 4-2 SAXS/D facility, two types of multilayers have been used: Mo/C on Si substrate, fabricated at Lawrence Berkeley Laboratory [S. Brennan *et al.*, Nucl. Instrum. Methods Phys. Res. A **347**, 417 (1994)] and Mo/B4C on Si substrate, obtained from Osmic, Inc. The energy bandpass of the former multilayer is about 150 eV at 10 keV, and that of the latter is expected to be slightly wider. A pair of the latter multilayers gives 8 x 10^{11} photons/s in a beam size 1 x 2 mm^2 (FWHM) at a photon beam energy of 9 keV and a SPEAR ring current of 85 mA. We will present excellent quality diffraction/scattering patterns from muscle fibers and protein solutions that show no significant smearing artifacts due to the wider energy bandpass.

Soft x-ray magneto-optic Kerr rotation and element-specific hysteresis measurement

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Soft x-ray magneto-optic Kerr rotation has been measured using a continuously tunable multilayer linear polarizer in the beam reflected from samples in applied magnetic fields. Like magnetic circular dichroism, Kerr rotation in the soft x-ray region can be element specific and much larger than in the visible spectral range when the photon energy is tuned near atomic core resonances. Thus sensitive element-specific hysteresis measurements are possible with this technique. Examples showing large Kerr rotation from an Fe film and element-specific hysteresis loops of the Fe and Cr in an Fe/Cr multilayer demonstrate these new capabilities. Some consequences of the strong anomalous dispersion near the Fe $L_{2,3}$ edges to the Kerr rotation measurement are discussed.

Interferometry using undulator sources R. Beguiristain, K. A. Goldberg, E. Tejnil, J. Bokor, H. Medecki, D. T. Attwood, and K. Jackson *Center for X-ray Optics, Lawrence Berkeley Laboratory, 1 Cyclotron Rd., MS 2-400, Berkeley, CA 94720* (Presented on 20 October 1995)

Optical systems for extreme ultraviolet (EUV) lithography need to use optical components with subnanometer surface figure error tolerances to achieve diffraction-limited performance [M.D. Himel, in *Soft X-Ray Projection Lithography*, A.M. Hawryluk and R.H. Stulen, eds. (OSA, Washington, D.C., 1993), **18**, 1089, and D. Attwood *et al.*, Appl. Opt. **32**, 7022 (1993)]. Also, multilayer-coated optics require at-wavelength wavefront measurement to characterize phase effects that cannot be measured by conventional optical interferometry. Furthermore, EUV optical systems will additionally require final testing and alignment at the operational wavelength for adjustment and reduction of the cumulative optical surface errors. Therefore, at-wavelength interferometric measurement of EUV optics will be the necessary metrology tool for the successful development of optics for EUV lithography. An EUV point diffraction interferometer (PDI) has been developed at the Center for X-Ray Optics (CXRO) and has been already in operation for a year [K. Goldberg *et al.*, in *Extreme Ultra Lithography*, D.T. Attwood and F. Zernike, eds. (OSA, Washington, D.C., 1994), K. Goldberg *et al.*, Proc. SPIE **2437**, to be published, and K. Goldberg *et al.*, J. Vac. Sci. Technol. B **13**, 2923 (1995)] using an undulator radiation source and coherent optics beamline at the Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory. An overview of the PDI interferometer and some EUV wavefront measurements obtained with this instrument will be presented. In addition, future developments planned for EUV interferometry at CXRO towards the measurement of actual EUV lithography optics will be shown.

Performance of x-ray optics at the European Synchrotron Radiation Facility

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This paper gives an overview of the challenges, the strategies, and the solutions in x-ray optics research and development at the European Synchrotron Radiation Facility (ESRF), followed by an account of the practical experience gathered on the beamlines. The performances of state-of-the-art mirrors, single-crystal monochromators, and multilayer structures are given. Amongst the topics are: adaptive optics and cryogenic cooling to cope with the heat load problem, Bragg-Fresnel optics for microfocusing, x-ray phase plates for polarization production and analysis, and the use of diamond crystals. It is shown that today's optical elements at the ESRF are capable of preserving the high quality of the present x-ray beams to a large extent.

Brilliance and flux reduction in imperfect inclined crystals

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The inclined crystal geometry has been suggested as a method of reducing the surface absorbed power density of high-heat-load monochromators for third-generation synchrotron radiation sources. Computer simulations have shown that if the crystals are perfectly aligned and have no strains then the diffraction properties of a pair of inclined crystals are very similar to a pair of conventional flat crystals with only subtle effects differentiating the two configurations. However, if the crystals are strained, these subtle differences in the behavior of inclined crystals can result in large beam divergences causing brilliance and flux losses. In this manuscript, we elaborate on these issues and estimate potential brilliance and flux density losses from strained inclined crystals at the APS.

Advantages of using a mirror as the first optical component for APS undulator beamlines

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The advantages of using a mirror as the first optical component for an Advanced Photon Source (APS) undulator beamline for thermal management, radiation shielding mitigation, and harmonic rejection are presented.

A monolithic, integrally cooled CVD SiC mirror substrate for high heat load applications

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The thermal loading on the optical components of third-generation synchrotron systems is putting severe restrictions on the design and materials of these components to ensure that they maintain their pointing and beam-forming characteristics. Recent advances in the properties and reliability of CVD silicon carbide, coupled with newly developed techniques in optical fabrication, have resulted in a monolithic, integrally cooled SiC mirror substrate model that can be manufactured at a cost that makes it viable. Two examples have been fabricated, and we report on their construction and characteristics, together with an assessment of the potential for extrapolating the design and the process to larger sizes.

Contact heat conductance at a diamond-OFHC copper interface with GaIn eutectic as a heat transfer medium

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The results of an experimental study of the contact heat conductance across a single diamond crystal interface with OFHC copper (Cu) are reported. Gallium-indium (GaIn) eutectic was used as an interstitial material. Contact conductance data are important in the design and the prediction of the performance of x-ray optics under high-heat-load conditions. Two sets of experiments were carried out. In one, the copper surface in contact with diamond was polished and then electroless plated with 1 μm of nickel, while in the other, the copper contact surface was left as machined. The measured average interface heat conductances are 44.7 ± 8 W/cm^2-K for nonplated copper and 23.0 ± 8 W/cm^2-K for nickel-plated copper. For reference, the thermal contact conductances at a copper-copper interface (without diamond) were also measured, and the results are reported. A typical diamond monochromator, 0.2 mm thick, will absorb about 44 W under a standard undulator beam at the Advanced Photon Source. The measured conductance for nickel-plated copper suggests that the temperature drop across the interface of diamond and nickel-plated copper, with a 20 mm ^{2} contact area, will be about 10°C. Therefore temperature rises are rather modest, and the accuracy of the measured contact conductances presented here are sufficient for design purposes.

Cooling solutions for high heat load optics

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Heat loads on optical components at third-generation synchrotron sources, such as the APS, present beamline designers with difficult and complex engineering problems. A number of solutions have been proposed, such as pin-post water cooling, cryogenic cooling, and liquid gallium cooling. This paper describes both a cryogenic cooling system and a liquid gallium pumping system that have been developed specifically for the APS high heat load beamlines. Also presented is a potential solution for the first mirrors on high heat load beamlines, based on liquid gallium internal cooling of a silicon carbide mirror.

A high-precision self-adapted optical structure

Zhibi Wang, Wenbing Yun, and Tuncer Kuzay *Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439* (Presented on 20 October 1995)

Third-generation synchrotron x-ray facilities, such as the Advanced Photon Source, generate a very high heat flux in a very small area. When an optical component is subjected to a heat load, there will be thermal deformation caused by a temperature increase. For a plate-like structure, the temperature difference over the thickness causes bending, and the average temperature increment causes axial deformation. For an optical element, the slope change due to bending is the main reason for the degradation of functionality in the optical component. In order to preserve photons, optical components have to be designed to have very small thermal deformation or small change of slope in the surface. Typically the change of slope is limited to a few microradians. The structure proposed here offers advantages in terms of cost, complexity, and operations.

On optimal contact cooling of high-heat-load x-ray mirrors

A. M. Khounsary and W. Yun *Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory, Argonne, IL* (Presented on 19 October 1995)

Under appropriate conditions, optimal contact cooling provides an attractive cooling strategy for the design of high-heat-load mirrors. This approach avoids a number of problems and uncertainties inherent in the fabrication, assembly, and operation of internally cooled high-heat-load optics. In this paper, the optimal contact-cooling concept is described, its advantages, disadvantages, and limitations are pointed out, and various design aspects and options are discussed. Simple heuristic guidelines for the design of such substrates are provided. The mirror assembly consists of the polished substrate and two cooling blocks in contact with it. The mirror and cooling block dimensions as well as the location of the cooling blocks on the mirror, are optimized to provide a thermo-mechanically balanced system so that there are negligible tangential slope errors in the mirror without any bending mechanism. As an example, the design of a high-heat-load first mirror for the Advanced Photon Source (APS) is described. This mirror, which is 1.2 m long, is exposed to a total power of 2 kW with a uniform heat flux of 0.38W/mm^2. This mirror is currently being fabricated. The concept of a thermo-mechanically balanced system can also be applicable to other high-heat-load optical components, such as monochromators.

Characterization of thermal distortion effects on beamline optics for EUV interferometry and soft x-ray microscopy

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This study analyzes synchrotron radiation heat loading effects on optical components of beamline BL12.0 for EUV interferometry and soft x-ray microscopy at the Advanced Light Source (ALS). Newly developed indirect side-cooled beamline optics were considered, and the resulting surface distortion of mirrors and grating indicates that there is no significant degradation of beamline performance in spectral resolution or throughput. Also analyzed are the effects of heat loading on end-station components, such as Fresnel zone plates, transmission gratings, masks and membranes. Experimental results of heat loaded membranes are presented as well in this writing.

Design and analysis of the internally cooled silicon mirrors and benders for wiggler sources at the Advanced Photon Source

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When silicon single crystal mirrors are bent to cylindrical figures of typically 6 km bending radius, the moments needed are very small and easy to disturb by cooling attachments to the sides of the mirror. Hence, we decided to abandon the conventional concept of cooling plates attached to the sides of the mirrors and instead have chosen to use internal water channels. We present here the design of mirrors with cooling channels near the neutral axis of the silicon beam that have a rather thick ''hot wall.'' The results of this analytical work are nonintuitive, regarding the stresses produced by wiggler heating. The design path chosen minimizes figure errors due to coolant pressure variations and residual stresses from machining and bonding of multiple layers of silicon. The geometry of the water channels avoids water-to-vacuum seals and uses the mirror bender as the coolant manifold. Engineering efforts, which reduce the bending stresses at bender-to-silicon interface by a factor of five, will be presented. The complete mirror bender and motion control mechanics will be shown.

Optimization of monochromator crystal bending designs using computer simulations

A. Frenkel,[†] B. Barg,[†] S. Heald[‡], K.H. Kim,[‡] F. Brown,[†] and E.A. Stern[†] [†]*Physics Department, Box 351560, University of Washington, Seattle, WA 98195* [‡]*Pacific Northwest Laboratories, Richland, WA 99352. Mailing address: Argonne National Laboratory, 9700 S. Cass Ave., Argonne, IL 60439* (Presented on 19 October 1995)

Sagittal focusing of a synchrotron radiation beam by cylindrically bending the second crystal in a double-crystal monochromator is an important way of increasing beam density at the sample posiion. In this paper we describe results obtained by finite element analysis of various optimized Si (111) crystal shapes. For the bending magnet and wiggler sources, we analyzed ribbed crystals and found conditions at which the sagittal curvature is cylindrical and the anticlastic effect is minimized. For the undulator A source, we found that a single slot in the center of a thick plate would be sufficient to eliminate the anticlastic effect and ensure cylindrical sagittal bending. Autofocusing of the beam by means of a trapezoidal slot was investigated, and simulation results are discussed.

$TaSi_2$-Si composites as wide-bandpass optical elements for synchrotron radiation

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The wide matrix rocking curves of the *in situ* eutectic composite $TaSi_2$-Si make it attractive as a wide-bandpass monochromator for synchrotron radiation. Wafers with Si[111], Si[110], or Si[100] orientation were studied to determine the origin of the wide rocking curves. The high degree of preferred orientation of the $TaSi_2$ rods relative to the Si matrix was examined using synchrotron Laue patterns and the $TaSi_2$ [100], $TaSi_2$ [003], and $TaSi_2$ [102] reflections. Double and triple axis diffractometry were used to show that the large widths were due to strain and mosaic and not long-range bending; copper radiation (for some double axis results) and 120 and 160 keV synchrotron radiation were used. At 8 keV, rocking curve widths were about twenty times broader than those from perfect Si, and peak reflectivities approached 20%. Rocking curves from Si[333] and Si[444] (120 and 160 keV, respectively) had identical profiles and reflectivities of about 25%. The triple axis results show compressive strains in the Si matrix along Si[111] (i.e., parallel to the rods) and dilational strains orthogonal to the rods. These results confirm the promise of $TaSi_2$-Si as a wide-bandpass optical element for synchrotron radiation.

Multilayer roughness and image formation in the Schwarzschild objective

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We present a study of the effect of multilayer-surface-roughness-induced scattering in the image formation of the Schwarzschild objective (SO) used in the spectromicroscope MAXIMUM. The two mirrors comprising the SO are coated with Ru/B_4C multilayers that have a peak reflectivity at 130 eV. We had long observed that a diffuse x-ray background surrounds the focused x-ray spot. The spatial resolution remains at 0.1 μm in spite of this. However, since a significant fraction of the flux is lost to the background, since too large an area of the sample is illuminated, and since the S/N ratio is degraded, the origins of this effect merit investigation. This diffuse background resulting from x-ray scattering at the surface of the mirrors was mapped out using bidirectional knife edge scans. Complementary surface roughness simulations were carried out with the ray-tracing program SHADOW. AFM experiments were also done to directly measure the surface roughness and power spectrum of representative multilayers. Following curve fitting, it was possible to classify Gaussian components in both the measured and simulated profiles as arising from scattering occurring at either the convex primary mirror or the concave secondary mirror. Together with geometrical analysis, these techniques permitted us to track the image formation process of an actual optical system in the presence of surface roughness.

Use of tapered glass capillaries for producing microbeams

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The Pacific Northwest Consortium CAT is developing tapered glass capillaries using fiber optics techniques for fabrication. Previous calculations showed that, under ideal conditions and using Undulator A as a source, glass capillaries can produce higher intensity gains than those of mirrors for an output diameter of 5 micrometer or less. Recently, we fabricated several capillaries with approximately linear tapers and tested three of them with outlet diameters of 1.3, 1.4, and 12.4 micrometers and lengths of about 35–90 cm. We obtained intensity gains over a pin hole of about 270, 240, and 30, respectively. They are about half of the calculated values expected from a perfectly linear profile. Also the angular spread of the output beam was much larger than the calculated value. We measured the profile of one capillary in detail and calculated the intensity for the capillary with the measured profile and still found significant differences. We also made calculations assuming several types of misalignment and found that they are important factors in understanding the larger angular divergence and reduced intensity. These results suggest improvements in the fabrication of the capillaries and in ways to support them during experiments.

High precision, high-heat-load mirror for the APS diagnostics beamline

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A high precision mirror for measuring the storage ring beam size is under fabrication for the APS diagnostics beamline. The mirror, which will be located at 12.9 meters from the bending magnet source, is required to maintain less than 1.6 microradian slope error. The mirror design consists of a slot in the center in order to reduce incident power from the 300-mA, 7-GeV beam during normal operation. Water channels with fins are machined in the GlidCop mirror body to protect it against extremely high heat loads under accidental beam deviations. The mechanical design of the mirror, and results from a thermal analysis are presented in this paper.

XOP: A graphical user interface for spectral calculations and x-ray optics utilities

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A graphical user interface, using the Interactive Data Language (IDL) widget toolkit, for calculation of spectral properties of synchrotron radiation sources and for interaction of x-rays with optical elements has been developed. The interface runs presently on three different computer architectures under the Unix operating system – the Sun-OS, the HP-UX, and the DEC-Unix operating systems. The point-and-click interface is used as a driver program for a variety of codes from different authors written in different computer languages. The execution of codes for calculating synchrotron radiation from undulators, wigglers, and bending magnets is summarized. The computation of optical properties of materials and the x-ray diffraction profiles from crystals in different geometries are also discussed. The interface largely simplifies the use of these codes and may be used without prior knowledge of how to run a particular program.

Design of a high precision mirror-rotation system at the Advanced Photon Source

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A prototype of a high precision rotation system has been designed, built, and tested for a horizontal deflecting mirror for the sector 2 undulator beamline at the Advanced Photon Source. The UHV high heat load mirror, which is the first optical element in the first optics enclosure, diverts undulator white beam to the downstream optics and experimental stations up to 47 meters away. Submicroradian positioning of this deflection arm is essential due to the position accuracy requirements at the experiment station and is accomplished using a differential-style actuator with a frictionless rotation platform mounted externally to the mirror chamber. The differential actuator combines a high gear-ratio mechanical drive with a series of bellows to achieve near-zero-backlash positioning. As a result, submicroradian resolutions are possible without the use of closed-loop controls. This paper presents the mechanical design and specifications of this system and discusses the prototype test results.

Optimization of multilayer reflectivity and bandpass for soft to hard x-ray applications [0.1–200 keV]

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In the last decades, the major motivation for manufacturing multilayer mirrors has been in soft x-ray applications, particularly for astronomy, microlithography, and polarimetry. The advent of high energy synchrotron storage rings has provided a new significant impetus emphasizing high energy applications and especially when flux, rather than resolution, is desired. In this paper we present the reflection properties of the most promising multilayer material combinations for the energy range from 0.1 keV up to 200 keV. Previous calculations by Rosenbluth were limited to a maximum of 2 keV and to multilayers composed of pure elements and operating under normal incidence. As alloys might be essential for a smooth growth and/or for stability under high heat load, our screening consisted of a list of up to 300 solids having a melting point above 100°C and that could be deposited in a sputtering process. A full computer search calculates 45000 multilayer combinations for each angle (or multilayer d-spacing) and energy of operation, the only necessary input variables. Other manufacture-related parameters can be specified to give a more realistic picture of the performance. As the number of layers is often limited, a nonperiodic design could minimize absorption effects.

Design and performance of a compact, versatile crystal bender for sagittal focusing of x-ray beams

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A focusing element that can be added to new and existing x-ray monochromators is described. The bender is used to focus 4 mrad of light into a 300 micron spot (4:1 demagnification). The focus is dynamically adjusted over the energy range 2.1 to 25 keV. This device is a working part of beamline X16C at the NSLS and is routinely used to collect surface diffraction, DAFS, and EXAFS data. Suggestions for its use in other beamlines, including insertion device lines at the APS, will be discussed.

Multilayer optics for harmonic control of angiography beamline sources

R. Tatchyn, T. Cremer, D. Boyers,[1] Q. Li,[1] and M. Piestrup[1] *Stanford Synchrotron Radiation Laboratory, Stanford Linear Accelerator Center, Stanford, CA 94304* [1]*Adelphi Technology, Inc., 2181 Park Blvd., Palo Alto, CA 94306* (Presented on 19 October 1995)

In recent work, multilayers with band-tailored optics for dual energy digital subtraction angiography (DDSA) applications have been designed and tested at SSRL. Control of various multilayer parameters, including period grading, ratio of high-to-low Z material thickness, number of layers, etc., was used to produce reflectors with bandwidths ranging from 0.6%–10% and efficiencies in the 30%–95% range. In this paper, we consider the control of multilayer bandshapes and the implementation of double-reflection multilayer configurations to further control the first harmonic (33 keV) bandwidth and to suppress or eliminate the 66 keV and 99 keV harmonics present on angiography beamlines driven by wiggler or micropole undulator sources.

Medical imaging

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There are a number of medically related imaging programs at synchrotron facilities around the world. The most advanced of these are the dual energy transvenous coronary angiography imaging programs, which have progressed to human imaging for some years. The NSLS facility will be discussed and patient images from recent sessions from the NSLS and HASYLAB will be presented. The effort at the Photon Factory and Accumulator Ring will also be briefly covered, as well as future plans for the new facilities. Emphasis will be on the new aspects of these imaging programs; this includes imaging with a peripheral venous injection of the iodine contrast agent, imaging at three photon energies, and the potential of a hospital-based compact source. Other medical programs to be discussed, are the multiple energy computed tomography (MECT) project at the NSLS and plans for a MECT program at the ESRF. Recently, experiments performed at the NSLS to image mammography phantoms using monochromatic beam have produced very promising results. This program will be discussed as well as some new results from imaging a phantom using a thin Laue crystal analyzer after the object to eliminate scatter onto the detector.

Deep x-ray lithography for micromechanics and precision engineering

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Micromechanics, an emerging technology for sensor and actuator fabrication, has a large market potential that has already been exploited in the sensor area. Progress in actuators, devices that modify their environment and are fundamentally three dimensional, has been much more modest and is suffering from the availability of a fabrication tool with the necessary attributes. If the tool is based on photoresist technology, requirements include very large structure heights: in the millimeter range, for mask-defined prismatic photoresist shapes with flanks that differ from 90 degrees by less than 15 arc-seconds. Photoresist procedures that lead to these results are very different from their counterparts in the microelectronic industry. Thus, application is based on precast sheets of polymethyl methacrylate, PMMA, and solvent bonding followed by precision fly-cutting. Exposure is based on well-collimated x-ray sources, synchrotrons, with flux densities that can deposit 1,600 Joules per cubic centimeter in a finite time at the correct photoresist depth. Since PMMA has an absorption length that varies with photon energy, it is 100 micrometer at 3000 eV and increases to 1 cm at 20,000 eV, beamline and exposure designs center on transmission filters that control the low energy portion of the synchrotron spectrum. Since exposure latitude is large, overexposure by a factor of 15 is allowed, beamline and exposure design are relatively simple. Experiments via the Wisconsin machine, Aladdin, and the Brookhaven 2.6-GeV ring are being used to study the effectiveness issue of manufacturing with synchrotron radiation. Actuator test vehicles are linear and rotational magnetic micromotors with force outputs in the milli-Newton range. High energy exposures have produced large parts with submicron precision that are finding applications in ink jet printing and precision injection molding procedures. Both device types are unique to x-ray assisted processing.

Preparation of microfocusing optics using synchrotron radiation sources

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X-rays are used for microfabrication of high-aspect-ratio structures because of their high penetrating power for microfabrication of integrated circuits because of their very high spatial resolution. An uncommon application is the development of phase-shifting optics for hard x-rays, where both requirements (high aspect ratio and high resolution) must be met at the same time. In the hard x-ray region (8 keV and up), conventional absorbing binary diffractive optics are very inefficient because of the low contrast of most elements. It is instead possible to achieve very high efficiency using phase-shifting optics. To achieve a phase shift of Pi, several microns of material are needed. At the same time, the spatial resolution is determined by the finest line in the pattern, of the order of 0.2–0.1 μm. This yields aspect ratios of 10-50, posing great challenges to microfabrication because the submicron dimensions require a much more delicate process than that found, for instance, in LIGA. We have overcome these hurdles, and succeeded in manufacturing Fresnel phase plates with 0.1 μm smallest features for operation at 8 keV. We use a combination of x-ray and electron-beam lithography to process the masks. In particular, the use of an x-ray aligner, capable of multiple exposures, has allowed us to fabricate multilevel FPPs, with ''blazed'' zone profile of efficiency approaching 80% in the first order focus. We will review the techniques that are at the basis of our fabrication process, describe our approach, and present some of the most recent results.

Toward the development of high resolution synchrotron x-ray diffraction tomography of polycrystalline materials

Stuart R. Stock, D. P. Piotrowski, A. Guvenilir, C. R. Patterson, and J. D. Haase *School of Materials Sci. & Eng., Georgia Institute of Technology, Atlanta, GA 30332-0245* Zofia U. Rek *SSRL, P.O. Box 4349, Bin 69, Stanford, CA 94309-0210* (Presented on 18 October 1995)

In understanding the macroscopic response of polycrystalline structural materials to loading, it is frequently essential to know both the three-dimensional distribution of strain and of microtexture. The methods must be nondestructive, however, if the evolution of quantities, such as strain at a fatigue crack tip, are to be studied. This paper describes approaches for high resolution synchrotron x-ray diffraction tomography of polycrystalline materials. Preliminary experiments are reported on partially cracked compact tension samples of Al-Li 2090 and on model samples of randomly packed, millimeter-sized single crystals. Polychromatic beams collimated to diameters as small as 30 μm have been used, and collecting the spatial distribution of diffracted intensity on image storage plates as a function of sample-to-detector separation allowed inference of the depth of the volume elements contributing to diffraction. The precision to which one can determine the depths of volume elements will be discussed as well approaches for three-dimensional, nondestructive strain mapping.

Installation and initial operation of the Suss Advanced Lithography Model 4 X-ray Stepper

Gregory M. Wells, J. P. Wallace, E. L. Brodsky, Q. J. Leonard, M. T. Reilly, P. D. Anderson, W. K. Lee, and F. Cerrina *Center for X-ray Lithography, University of Wisconsin, 3731 Schneider Dr., Stoughton, WI 53589* Klaus Simon *Suss Advanced Lithography* (Presented on 18 October 1995)

A Suss Advanced Lithography X-ray Stepper designed as a production tool for high throughput in the sub-quarter-micron device range has been installed and is being commissioned at the University of Wisconsin's Center for X-ray Lithography (CXrL). Illumination for the stepper is provided by a scanning beamline designed and constructed at CXrL. The beamline optical components are a gold-coated plane mirror, a 1-micron-thick silicon carbide window, and a 25-micron-thick beryllium exit window. Beamline features include synchronized scanning of the mirror and exit window, variable scan velocity to compensate for reflectivity changes as a function of incident angle, and a horizontal oscillation of the beryllium window during vertical scanning to average the effects of nonuniform beryllium window transmission. A helium purged snout transports the x-rays from the beamline exit window, to the exposure plane in the stepper. This snout is retractable to allow for the loading and unloading of masks into the stepper. The motions of the mirror, exit window, and snout are computer controlled by a LABVIEW program that communicates with the stepper control software. The design of the beamline and initial operating experiences with the beamline and stepper will be discussed.

Precision manufacturing using LIGA Keith H. Jackson and Chantal Khan Malek *Center for X-ray Optics, Lawrence Berkeley Laboratory, Berkeley, CA 94720* William D. Bonivert, J. M. Hruby, and J. T. Hachman *Materials Synthesis Department, Sandia National Laboratory, Livermore, CA 94551* Reid A. Brennen, Dean Wiberg, and Michael H. Hecht *Center for Space Microelectronics Technology, Jet Propulsion Laboratory, Pasadena, CA 91109-8099* (Presented on 18 October 1995)

Our objective is the fabrication of small high-precision parts using LIGA, which can be used in a variety of industrial applications. LIGA is a combination of deep x-ray lithography, electroplating, and replication processes that enables the fabrication of microstructures with vertical dimensions several millimeters high, lateral dimensions in the micrometer range, and submicron tolerances. On beamline 10.3.2, at the Advanced Light Source (ALS), the Center for X-ray Optics (CXRO) has built an end station suitable for LIGA. The ALS is an excellent source of radiation for this application. The CXRO, in close collaboration with Sandia National Laboratory and the Jet Propulsion Laboratory, has developed the other essential process steps of mask making, resist development, x-ray exposure, and electroplating. This technology provides a powerful tool for mass production and miniaturization of mechanical systems into a dimensional regime not accessible by traditional manufacturing operations. We will present several applications that exploit the characteristics of the LIGA process: the fabrication of magnetic laminations for a high precision stepping motor; miniature octopole lens for advanced e-beam lithography; high-aspect-ratio x-ray collimating grids for astronomy; and microscopic tumblers for nuclear security.

A new scanning photoemission microscope for ELETTRA: SuperMAXIMUM

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High brightness, third-generation synchrotrons allow diffraction-limited performance and large flux for scanning photoemission microscopes. A new microscope, SuperMAXIMUM, is being developed at the University of Wisconsin Center for X ray Lithography in collaboration with the Sincrotrone Trieste. The beamline, being built in Trieste, uses a variable angle spherical grating monochromator (VASGM). A combination of rotation of a plane mirror and rotation of the spherical grating keeps the slit positions and beam directions fixed. The microscope objectives are normal-incidence, multilayer-coated Schwarzschild objectives. The project, which is nearing completion, utilizes novel designs for optics alignment, sample rastering mechanics, and software control. We will discuss the project status, new designs, and techniques.

Installation of the MAXIMUM microscope at the ALS

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The MAXIMUM scanning x-ray microscope, developed at the Synchrotron Radiation Center (SRC) at the University of Wisconsin – Madison, was implemented on the Advanced Light Source (ALS) in August of 1995. The microscope's initial operation at SRC successfully demonstrated the use of a multilayer-coated Schwarzschild objective for focusing 130 eV x-rays to a spot size of better than 0.1 micron with an electron energy resolution of 250 meV. The perfor-

mance of the microscope was severely limited because of the relatively low brightness of SRC, which limits the available flux at the focus of the microscope. The high brightness of the ALS is expected to increase the usable flux at the sample by a factor of 1000. We will report on the installation of the microscope on bending magnet beamline 6.3.2 at the ALS and the initial measurement of optical performance on the new source, and preliminary experiments on the surface chemistry of HF-etched Si will be described.

X1A: Second-generation undulator beamlines serving soft x-ray spectromicroscopy experiments at the NSLS

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The X1A undulator beamline is being rebuilt with two separate monochromators on its two branches. The new arrangement will deliver spatially coherent beams to imaging experiments, with spectral resolving power of up to 5000, and the capability to optimize the resolving power versus flux. The beamlines will operate simultaneously, and each will use 15 percent of the undulator beam, yet deliver high coherent flux. Because of the small beam divergence, the spherical grating monochromators can operate with fixed exit arms throughout the 250–800 eV range.

X-ray fluorescence analysis with high energy resolution

Wolfgang A. Caliebe,[†] Saša Bajt,[‡] and Chi-Chang Kao[†] [†]*National Synchrotron Light Source, Brookhaven National Laboratory, Upton, NY 11973* [‡]*The University of Chicago and Center for Advanced Radiation Sources, Chicago, IL 60637* (Presented on 18 October 1995)

The analysis of x-ray fluorescence lines with total energy resolution of 1 eV or better can provide detailed information on the electronic structure of the sample in addition to quantitative elemental analysis of the sample. A perfect crystal spectrometer was developed for this purpose. Preliminary results from a series of chromium oxides will be presented.

Trace element analysis using the fluorescence microprobe at the Advanced Light Source

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The fluorescence microprobe beamline at the Advanced Light Source (ALS) is a unique instrument for analysis of trace elements. The beamline is on a bending magnet port of the synchrotron and uses a pair of multilayer-coated mirrors to focus the x-ray source to a spot size of 1–5 μm^2. Since the multilayer mirrors limit the energy bandpass of the system to 5–10%, the trace element sensitivity is significantly improved compared to the use of grazing incidence mirrors. Different pairs of mirrors have been used to operate at 8.5, 10, and 12.5 keV. The detection limits for elements from Si to As will be presented for operation at both 1.5 GeV and 1.9 GeV. Results that illustrate the features of the instrument will be presented from the many samples that have been studies.

Focusing x-rays to a 1 μm spot using elastically bent, graded multilayer-coated mirrors

J. H. Underwood,* A. C. Thompson,* J. B. Kortright,* K. C. Chapman,* and D. Lunt[†] **Center for X-ray Optics, Lawrence Berkeley National Laboratory, Berkeley, CA 94720* [†]*Photon Sciences Ltd., 32 Athol St., Douglas, Isle of Man, British Isles* (Presented on 18 October 1995)

In the LBNL x-ray fluorescence microprobe, a synchrotron source of x-rays is demagnified several hundred times using a pair of mirrors in the Kirkpatrick-Baez configuration. These are coated with multilayers to increase reflectivity and limit the pass band of the x-rays striking the sample. With spherical mirrors, the spot size obtained is limited by spherical aberration. This can be corrected by using an initially flat mirror elastically bent by a combination of end couples into an ellipse. By grading the multilayer coatings in d-spacing, the throughput of the focusing system is increased and the pass band narrowed. A pair of such mirrors, installed in the microprobe on a bending magnet at the Advanced Light Source (ALS), achieved focal spots of dimensions 1μm×1 μm at energies of 8.5 keV and 12 keV, with an energy pass band of 10%.

Phase-contrast computed microtomography with 50 keV synchrotron x-rays

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The possibilities to determine the internal structure of low density materials by a simple microtomography setup with high energy synchrotron x-rays are demonstrated experimentally. The coherent properties of a 50 keV x-ray beam at the ESRF wiggler beamline are used to observe phase-contrast images of a boron fiber, which has negligible absorption in this energy range. Images of the boron fiber are recorded with a high-resolution x-ray film at various distances up to 2 m. For microtomography studies, 61 images are taken over an angular range of 180 degrees. In the reconstructed cross sections, the hollow, 15-mm-diameter core of the fiber is clearly visible.

EUV and soft x-ray transmission microscope R. N. Watts, T. B. Lucatorto, and S. T. Liang *National Institute of Standards and Technology, Physics Building (221), Room A253, Gaithersburg, MD 20899* F. Polack *IOTA/LURE, BAT 503, BP 147, 91403, Orsay, Cedex, France* M. R. Scheinfein *Dept. of Physics & Astronomy, Arizona State University, Tempe, AZ 85287* (Presented on 18 October 1995)

We present preliminary performance results for a new type of imaging microscope operating in the EUV and soft x-ray regions. This microscope is a true transmission microscope in which an unmagnified image of the sample is formed by differential absorption of

the x-ray beam as it passes through the sample. The unmagnified photon image is converted into low energy secondary electrons at a thin CsI photocathode, and the subsequent electron pattern is magnified and imaged using a simple 3-lens system. Conversion of the magnified electron patern into visible photons occurs at a fine grain phosphor viewed by a CCD detector/computer combination that allows parallel detection of the original photon image in near real time with approximately 1000× magnification. The microscope has a theoretical resolution of 20 nm and a potentially wide range of uses including biology, materials science studies, and investigations into magnetic dichroism effects. The design and preliminary imaging results of the microscope will be presented and future directions discussed.

Monochromatic beam mammography studies using synchrotron radiation Nicholas F. Gmür and W. Thomlinson *National Synchrotron Light Source, Brookhaven National Laboratory, Building 725D, Upton, NY 11973-5000* R. E. Johnson, D. Washburn, and E. Pisano *University of North Carolina, Chapel Hill, NC 27599* F. Arfelli *National Synchrotron Light Source, Upton, NY 11973-5000 and INFN di Trieste and Università di Trieste, Trieste, Italy* L. D. Chapman, R. Menk, and Z. Zhong *National Synchrotron Light Source, Upton, NY 11973-5000* D. Sayers *North Carolina State University, Raleigh, NC 27695* (Presented on 18 October 1995)

Preliminary experiments have been carried out on the X27C R&D beamline at the National Synchrotron Light Source (NSLS) to explore the potential improvement in contrast in breast imaging using monochromatic synchrotron x-rays [R. E. Johnson *et al.*, SPIE (1995) (to be published)]. In our present study, images have been obtained of ACR, contrast detail and anthropomorphic phantoms at 16 to 24 keV. Phantom thickness varied from 42 to 80 mm. Synchrotron images using a Fuji image plate detector and standard mammographic film have been compared to each other and with conventionally produced images. The preliminary results show an improved contrast over the conventional images with lower absorbed dose in the phantoms. The image plate detector was used for our fist experiments because it was readily available and produces digital data. Experiments using an additional analyzer crystal as a scatter rejection element are also underway at the NSLS [D. Chapman, SRI '95 (these proceedings)]. We plan to evaluate a variety of detectors and monochromatic beam geometries in order to develop a system that optimizes mammography image contrast and spatial resolution.

Mammography imaging studies using a Laue crystal analyzer D. Chapman (1), W. Thomlinson (2), F. Arfelli (2,4), N. Gmür (2), Z. Zhong (2), R. Menk (2), R. E. Johnson (3), D. Washburn (3), E. Pisano (3), and D. Sayers (5) *(1) CSRRI, Illinois Institute of Technology, 3301 S. Dearborn, Chicago, IL 60616 (2) National Synchrotron Light Source, Brookhaven National Laboratory, Upton, NY 11973 (3) University of North Carolina, Chapel Hill, NC 27599 (4) INFN di Trieste and Università di Trieste, Trieste, Italy (5) North Carolina State University, Raleigh, NC 27695* (Presented on 18 October 1995)

Synchrotron-based mammography imaging experiments have been performed with monochromatic x-rays in which a Laue crystal placed after the object being imaged has been used to split the beam transmitted through the object. The X27C R&D beamline at the National Synchrotron Light Source was used with the white beam monochromatized by a double crystal Si(111) monochromator tuned to 18 keV. The imaging beam was a thin horizontal line approximately 0.5 mm high by 100 mm wide. Images were acquired in line scan mode with the phantom and detector both scanned together. The detector for these experiments was an image plate. A thin Si(111) Laue analyzer was used to diffract a portion of the beam transmitted through the phantom before the image plate detector. This ''scatter free'' diffracted beam was then recorded on the image plate during the phantom scan. Since the thin Laue crystal also transmitted a fraction of the incident beam, this beam was also simultaneously recorded on the image plate. The imaging results are interpreted in terms of an x-ray schliere or refractive index inhomogeneities. The analyzer images taken at various points in the rocking curve will be presented.

Pixel array detector for time-resolved x-ray scattering Brian G. Rodricks *Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439* Sandor L. Barna, Sol M. Gruner, John A. Shepherd, Mark W. Tate, and Robert L. Wixted *Department of Physics, Princeton University, Princeton, NJ 08544* (Presented on 20 October 1995)

This paper describes the development of a large area hybrid pixel detector designed for time-resolved synchrotron x-ray scattering experiments in which limited frames, with a high framing rate, are required. The final design parameters call for a 1024×1024 pixel array device with 150-micron pixels that is 100% quantum efficient for x-rays with energy up to 20 keV, with a framing rate in the microsecond range. The device will consist of a fully depleted diode array bump bonded to a CMOS electronic storage capacitor array with eight frames per pixel. The two devices may be separated by a x-ray blocking layer that protects the radiation-sensitive electronics layer from damage. The signal is integrated in the electronics layer and stored in one of eight CMOS capacitors. After eight frames are taken, the data are then read out, using clocking electronics external to the detector, and stored in a RAM disk. Results will be presented on the development of a prototype 4×4 pixel electronics layer that is capable of storing at least 10,000 12-keV x-ray photons for a capacity of over 50 million electrons with a noise corresponding to 2 x-ray photons per pixel. The diode detective layer and electronics storage layer along with the radiation damage and blocking layers will be discussed.

High-resolution multielement solid-state detectors Alberto Pullia *Dipartimento di Elettronica e Informazione, Politecnico di Milano, Piazza L. Da Vinci, 32, 20133 Milano, Italy* L. Furenlid, H.W. Kraner, P.J. Pietraski, and D.P. Siddons *Brookhaven National Laboratory, Upton, NY 11973* (Presented on 20 October 1995)

Recent advances in multielement solid-state detector systems for high rate, high resolution x-ray spectroscopy at noncryogenic temperatures will be described in this paper. A 16-channel silicon detector system, designed and built at BNL, has been recently operated in the NSLS machine beam #X19A, showing an average energy resolution of less than 250 eV FWHM, which is adequate to discriminate the fluorescence trace element against the background of elastically scattered photons in a typical EXAFS application. A larger, 128 channel system, will soon permit a higher overall count rate: $>10^6$ counts per second. It is shown that, in order to achieve high resolution with a solid-state detector, special care must be spent in the detector-preamplifier assembly. A low noise detector-preamplifier may be obtained integrating the front-end devices (an FET and/or a feedback capacitor) with the detector itself.

Macromolecular crystallographic results obtained using a 2048 ×2048 CCD detector at CHESS

Daniel J. Thiel,[a] Steven E. Ealick,[a] Mark W. Tate,[b] Sol M. Gruner,[b] and Eric F. Eikenberry[c] *a) Section of Biochemistry, Cell and Molecular Biology, Cornell University, Ithaca, NY 14853 b) Department of Physics, Princeton University, Princeton, NJ 08544 c) Robert Wood Johnson Medical School, Piscataway, NJ 08854* (Presented on 18 October 1995)

We present results of macromolecular crystallographic experiments performed at the Cornell High Energy Synchrotron Source (CHESS) with a new CCD-based detector. This detector, installed in January 1995, complements a 1024×1024 CCD detector that has been in continuous operation at CHESS since December 1993. The new detector is based on a 4-port, 2048×2048 pixel CCD that is directly coupled to a Gd_2O_2S:Tb phosphor by a 3:1 tapered fiber optic. The active area of the phosphor is a square 82 mm on an edge. The readout time is 7 seconds. In the standard mode of operation, the pixel size at the active area is 41 μm on the edge leading to the capability of resolving approximately 200 orders of diffraction across the detector face. The detector also operates in a 1024×1024 mode in which the pixel size is electronically increased by a factor of 4 in area resulting in smaller data files and faster detector readout but at the expense of spatial resolution. Most of the data that has been collected by this detector has been collected in this mode. Dozens of data sets have been collected by many experimenters using this detector at CHESS during the four month period from its installation until the start of the six-month down period of the storage ring. The capabilities of the detector will be illustrated with results from various crystallographic measurements including experiments in which the recorded diffraction patterns extend in resolution as far as 1 Å. The results demonstrate that this detector is capable of collecting data of quality at least equal to that of imaging plates but, in many circumstances, with much greater beamline efficiency.

Siemens SMART CCD detector applied to protein crystallography with synchrotron and rotating anode x-ray sources

J. Phillips, J. Chambers, J. Fait, M. Schuster, and R. Sparks *Siemens Analytical Instruments, 6300 Enterprise Lane, Madison, WI 53719-1173* (Presented on 18 October 1995)

The performance of the Siemens CCD detectors with 1K and 2K chips is evaluated using radiation from bending magnet beamlines at SSRL and NSLS and from a rotating anode source with three types of optics. Structure solution quality data are obtainable in short times for macromolecular (up to 300 Å cell) and small molecule crystallography. General experiments, such as time-resolved powder diffraction and overlayer diffraction are also possible.

TEXRAY™ CCD detectors

Joseph D. Ferrara, K. Crane, R. D. Gardner, N. D. Jones, J. W. Pflugrath, J. M. Troup, and B. R. Vincent *Molecular Structure Corporation, 3200 Research Forest Drive, The Woodlands, Texas 77381* (Presented on 18 October 1995)

We have designed and built TEXRAY™ CCD detectors with properties suitable for single-crystal data collection on both small molecules and macromolecules. Characterization and use of 70 mm×70 mm and 140 mm×140 mm aperture detectors will be discussed in the context of the synchrotron source.

Position sensitive x-ray detector OD-3

V.M. Aulchenko, Yu.S. Velikzhanin, V.M. Titov, S.A. Ponomarev, Yu.V. Usov, M.S. Dubrovin, *B.P. Tolochko, Yu.A. Gaponov, A.I. Ancharov, O. Evdokov, and A.V. Besserguenev *Budker Institute of Nuclear Physics *Institute of Solid State Chemistry 630090, Novosibirsk 90, Russia* (Presented on 18 October 1995)

A fast one-coordinate x-ray detector of a new design aimed for angular measurements in diffraction experiments was developed in BINP. The detector is based on a multiwire proportional chamber with x-ray absorption drift volume. It allows acceptance of photons in the energy range from 6 keV to 20 keV with a maximum rate of 10 MHz/detector and coordinate resolution about 0.1 mm (rms) in linear scale. The first OD-3 chamber has a 0.4-mm-thick Be inlet window 200 mm x 10 mm, a photoabsorbtion length of 50 mm, and a parallax-free cathode structure for angles up to ±15 degrees at variable focal length (from 300 mm to 450 mm without any modification and to infinite at cathode plane replacement). The first tests of the detector at synchrotron radiation beamline 5-b VEPP-3 and with a x-ray tube show a good performance. The detector construction specifics and test results will be discussed in the report.

Progress in multielement silicon detectors for synchrotron XRF applications

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Multielement silicon strip detectors, in conjunction with integrated circuit pulse-processing electronics, offer an attractive alternative to conventional lithium-drifted silicon and high purity germanium detectors for high count rate, low noise synchrotron x-ray fluorescence applications. We have been developing these types of detectors specifically for low noise synchrotron applications, such as extended x-ray absorption fine structure spectroscopy, microprobe x-ray fluorescence and total reflection x-ray fluorescence. The current version of the 192-element detector and integrated circuit preamplifier, cooled to −25 °C with a single-stage thermoelectric cooler, achieves an energy resolution of <200 eV FWHM (at 5.9 keV, 2 microseconds peaking time), and each detector element is designed to handle a ~20 kHz count rate. The detector system will soon be completed to 64 channels using new IC amplifier chips, CAMAC ADCs, CAMAC histogramming modules, and Macintosh-based data acquisition software. We will report on the characteristics of this detector system, the characteristics of the next generation system (192 channels with IC ADCs), and the use of these detector systems in synchrotron XRF applications.

A multichannel monolithic Ge detector system for fluorescence x-ray absorption spectroscopy

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The construction and performance characteristics of a monolithic quad-pixel Ge detector designed specifically for fluorescence x-ray absorption spectroscopy (XAS) at synchrotron radiation sources is described. The detector semiconductor element has an active surface area of 4.0 cm^2 that is electrically separated into four

1.0 cm^2 pixels, with little interfacial dead volume. The spatial response of the array demonstrates that cross-talk between adjacent pixels is less than 10% for 5.9-keV photons that fall within 0.5 mm of the pixel boundaries. The detector electronics system utilizes preamplifiers built at LBNL with commercial Tennelec Model TC 244 amplifiers. Employing an ^{55}Fe test source (Mn K_α, 5.9 keV), energy resolution of better than 200 eV is achieved with a 4 msec peaking time. At 0.5 msec peaking time, pulse pileup results in a 75% throughput efficiency for an incoming count rate of 100 kHz. Initial XAS fluorescence measurements at the beamline 4 wiggler end stations at SSRL show that the detector system has several advantages over commercially available x-ray spectrometers for low-concentration counting applications.

X-ray polarization detector Ping-Shine Shaw, Uwe Arp, and Albert Henins *National Institute of Standards and Technology, Building 221, Room B206, Gaithersburg, MD 20899* Steve Southworth *Physics Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439* (Presented on 18 October 1995)

We designed and constructed a cylindrical gas proportional counter that can be used to analyze the linear polarization of x rays with a wide range of energy from 2 keV to 10 keV. The polarization sensitivity is based on the highly nonisotropic scattering of polarized x rays from a gas or solid target. The gas proportional counter surrounds the scattering chamber and measures the scattered x rays as a function of the azimuthal angle. The angle of scattered x rays is determined by the charge division of the anode resistive wire. This polarimeter without any moving parts can measure x rays with continuous energies. It is specially suitable for synchrotron x rays. We discuss the testing and performance of such an x-ray polarimeter.

Polarization characteristics of silicon photodiodes and their dependence on oxide thickness
Terubumi Saito,[a] Lanny R. Hughey, James E. Proctor, and Thomas R. O'Brian *National Institute of Standards and Technology (NIST), B119 Radiation Physics, Gaithersburg, MD 20899* [a] *on leave from Electrotechnical Laboratory (ETL), 1-1-4, Umezono, Tsukuba-shi, Ibaraki 305, Japan* (Presented on 18 October 1995)

We have studied the polarization dependence of silicon photodiode responsivity as a function of wavelength, the angle of incidence, and the thickness of the silicon dioxide overlayer. The experimental results in the spectral region where there is no absorption in the silicon dioxide are explained well by a purely optical model. The responsivity dependence on polarization in the VUV is found to be smaller than that predicted and to be explainable by the presence of charge injection from the silicon dioxide layer.

Evaluation of Au/GaAsP and Au/GaP Schottky photodiodes as radiometric detectors in the EUV
R. E. Vest and L. R. Canfield *Electron and Optical Physics Division, Physics Laboratory, National Institute of Standards and Technology, Gaithersburg, MD 20899* (Presented on 18 October 1995)

Many applications of synchrotron radiation require an absolute measurement of photon flux. Schottky photodiodes consisting of a thin Au film deposited on GaAsP or GaP are sensitive to radiation in the extreme ultraviolet (EUV) and may be considered for use as radiometric transfer standard detectors. A radiometric detector should exhibit high quantum efficiency, spatial uniformity, resistance to radiation-induced changes, and temporal stability. While Au/GaAsP and Au/GaP Schottky photodiodes display high sensitivity, good uniformity, and resistance to radiation damage, they suffer from temporal instability. Results presented in this paper indicate that the quantum efficiency of Au/GaAsP and Au/GaP photodiodes degrades in the region from 50 nm to 150 nm during normal storage and is unstable at wavelengths as long as 254 nm. This loss of sensitivity is not substantially affected by ambient humidity and may be affected by heating the device. While useful as detectors, Au/GaAsP and Au/GaP Schottky photodiodes are not suitable for use as transfer standards in this spectral region and may not be suitable for other applications in which detector efficiency must be stable over periods longer than a week.

A 2D smart pixel detector for time-resolved crystallography
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A smart pixel detector is being developed for time-resolved crystallography for biological and material science applications. Using the pixel detector presented here, the Laue method will enable the study of the evolution of structural changes that occur within a protein as a function of time. The x-ray pixellated detector is assembled to the integrated circuit through a bump bonding process. Within a pixel size of 150×150 mm^2, a low-noise preamplifier-shaper, a discriminator, a 3-bit counter and the readout logic are integrated. The readout, based on the column architecture principle, will accept hit rates above $5\times10^8/cm^2/s$ with a maximum hit rate per pixel of 1 MHz. This detector will allow time-resolved Laue crystallography to be performed in a frameless operation mode, without dead time. Target specifications, architecture, and preliminary results on a 8×8 prototype are presented.

Recent advances in synchrotron-based Mössbauer experiments
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As the field of nuclear resonant scattering using synchrotron radiation matures, we see a shift from experiments designed to verify theoretical predictions towards those designed to use the phenomenon to elucidate the behavior of a sample. In parallel with this trend towards applications, we have seen further instrumental developments that extend the range of possible applications. This paper will review the recent work in this field with an emphasis on new sources, new isotopes, and new instrumentation.

Inelastic nuclear resonant scattering at the Advanced Photon Source
W. Sturhahn, T. S. Toellner, K. W. Quast, R. Röhlsberger, and E. E. Alp *Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois 60439* (Presented on 19 October 1995)

It is demonstrated how inelastic nuclear resonant scattering can be used for the investigation of lattice dynamics. The required instruments are explained. The feasibility of measuring a variety of nuclear resonances is discussed with respect to the synchrotron radiation intensity at the Advanced Photon Source.

Inelastic x-ray scattering at the National Synchrotron Light Source

C.-C. Kao, W. A. Caliebe, and J. B. Hastings *National Synchrotron Light Source, Brookhaven National Laboratory, Upton, New York 11973* K. Hämäläinen *Department of Physics, P.O. Box 9, FIN-00014 University of Helsinki, Finland* M. H. Krisch *European Synchrotron Radiation Facility, F-38043 Grenoble Cedex, France* (Presented on 19 October 1995)

The research program at the inelastic x-ray scattering beamline at the National Synchrotron Light Source is focused on the study of elementary excitations in condensed matter with total energy resolution on the order of 0.1 eV to 1.0 eV. Results from selected experiments are reported to demonstrate the capability of the beamline as well as the information that can be obtained from inelastic x-ray scattering experiments. © *1996 AIP.*

Fluorescence dynamics of biological systems using synchrotron radiation

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A beamline for time-resolved fluorescence spectroscopy of biological systems is under construction at the Synchrotron Radiation Center. The fluorometer, operating in the frequency domain, will take advantage of the time structure of the synchrotron radiation light pulses to determine fluorescence lifetimes. Using frequency-domain techniques, the instrument can achieve an ultimate time resolution on the order of picoseconds. Preliminary experiments have shown that reducing the intensity of one of the fifteen electron bunches in the storage ring allows measurement of harmonic frequencies equivalent to the single-bunch mode. This mode of operation of the synchrotron significantly extends the range of lifetimes that can be measured. The wavelength range (encompassing the visible and ultraviolet), the range of measurable lifetimes, and the stability and reproducibility of the storage ring pulses should make this beamline a versatile tool for the investigation of the complex fluorescence decay of biological systems. © *1996 AIP.*

Characterization of x-ray spatial coherence and its propagation

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X-ray beams of varying degrees of partial spatial coherence have been prepared and characterized, and the diffraction of these beams from patterned surfaces measured. The experiments were carried out at a bending magnet source at the NSLS (X-19C). The resulting diffraction patterns for a pair of slits and an optical grating are analyzed in terms of an x-ray mutual coherence function used to describe the propagation of the coherent wave front in the visible light regime. The diffraction and speckle pattern from the surface are the result of the mutual coherence function convoluted with the interference function of the grating. Forming diffraction patterns, or x-ray speckles, with partially coherent x-rays relaxes the requirement for the interference, thereby increasing the ''effective'' coherent flux. This detailed knowledge of the propagation of the x-ray spatial coherence aids in defining the physical characteristics of beamline optical elements that must preserve the coherent x-ray wave front. © *1996 AIP.*

Polarization measurement and vertical aperture optimization for obtaining circularly polarized bend-magnet radiation

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Using multilayer linear polarizers, we have characterized the polarization state of radiation from bend-magnet beamline 9.3.2 at the Advanced Light Source as a function of vertical opening angle at photon energies of 367 and 722 eV. Both a fine slit and a coarse semi-aperture were stepped across the beam to accept different portions of the vertical radiation fan. Polarimetry yields the degree of linear polarization directly and the degree of circular polarization indirectly assuming an immeasurably small amount of unpolarized radiation based on the close agreement of the theoretical and experimental results for linear polarization. The results are in good agreement with theoretical calculations, with departures from theory resulting from uncertainty in the effective aperture of the measured beam. The narrow 0.037-mrad aperture on the orbit plane transmits a beam whose degree of linear polarization exceeds 0.99 at these energies. The wide semi-aperture blocking the beam from above and below transmits a beam with a maximum figure of merit, given by the square root of flux times the degree of circular polarization, when the aperture edge is on the orbit plane thus blocking only half of the total available flux. © *1996 AIP.*

X-ray resonant magnetic scattering ellipsometer

Z. Xu, K. J. Randall, and E. Gluskin *Advanced Photon Source, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439* C.-C. Kao, E. D. Johnson *National Synchrotron Light Source, Brookhaven National Laboratory, Upton, New York 11973* C.T. Chen* *AT&T Bell Laboratories, Murray Hill, New Jersey 07974 *Present address: Synchrotron Radiation Research Center, No. 1, R&D Road VI, Hsinchu Science-Based Industrial Park, Hsinchu 30077, Taiwan, R.O.C.*

It is very difficult to characterize the polarization of a synchrotron radiation source in the soft and/or intermediate x-ray energy region particularly from 1 to 2 keV. Conventional multilayer mirror or single-crystal polarimeters do not work over this energy region because their throughput (the reflectivities combined with the phase shift) becomes insignificant. In this paper, we present a new ellipsometer scheme that is able to fully characterize the polarization of synchrotron radiation sources in this energy region. It is based on the dichroic x-ray resonant ferromagnetic scattering that yields in-

formation on both the polarization of the x-ray and the material (element specific) dielectric-constant tensor [C.-C. Kao *et al.*, Phys. Rev. B **50**, 9599 (1994)] due to the interband ferromagnetic Kerr effect [B.R. Cooper, Phys. Rev. A **139**, 1504 (1965)].

Soft x-ray interferometry

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The development of soft x-ray mirrors and large aperture soft x-ray beamsplitters now allows the near routine operation of soft x-ray interferometers with high brightness x-ray sources. Mach-Zehnder and Fourier transform interferometers utilizing a soft x-ray laser light source operating at 80 eV will be described. Results from high density, long scale-length plasma probing measurements, x-ray laser coherence measurements, and materials properties measurements will be presented.

Experimental station for inelastic scattering spectroscopy of electronic excitations

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An experimental station for inelastic x-ray scattering spectroscopy (IXSS) of phonons and electronic excitation is being built on the undulator beamline of Sector 3 at the Advanced Photon Source. The subject of the present article is a description of the instrumentation for the spectroscopy of electronic excitations. The goal of this program is to provide users with the possibility to study IXSS in low- and middle-Z materials with an energy resolution from 1 eV (with a beam coming directly from the high-heat-load monochromator to the specimen) to 100 meV (with a second channel-cut monochromator) in the energy transfer range of 200 eV. The optical scheme of the station is described, and status of the station is reported.

The multicrystal modular spectrometer for x-ray diffraction studies using SR

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We suggest a set of elements united in the modular x-ray spectrometer to easily implement multiaxis, multipurpose x-ray diffraction schemes, multiple-diffraction layouts with two-dimensional collimation of the incident beam, surface diffraction schemes, and experiments with various modifications of the x-ray standing wave method. The main elements of the spectrometer are: the one-circle goniometer with the vertical axis, the multicircle research goniometer, and different slit systems. All units except the multicircle goniometer can be mounted on two parallel optical guides. The multicircle goniometer is a stand-alone unit consisting of an Eulerian cradle mounted on a two-circle goniometer. All rotations are driven by stepping motors via worm gears. On axes where fine (to 0.1 arc sec or less) angular positioning is desirable, torsion-element-based rotation is used; it is driven via piezo drivers. A program package was developed to control the experiments. The software is based on the modular principle providing for fast implementation of application programs suited for specific x-ray diffraction methods. The results of multiple-diffraction studies with the use of the instrument are presented.

Anomalous small angle x-ray scattering study of layered silicate clays containing Ni(II) and Er(III)

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These studies concern the synthesis of heterogeneous catalysts and the incorporation of heavy metals in trapping media. The Ni(II) containing clays were synthesized at 200 °C whereas those containing Er(III) were ion-exchanged natural clays. For the first system, ASAXS data were measured at 5 different energies near the $K\alpha$ edge of Ni at three different reaction times: unreacted, 4 hrs, and 15 hrs when the crystallization is essentially complete. The data for the unreacted sample showed no correlations for a lamellar particle, while that reacted for 4 hrs indicated the evolution of lamella, and the crystallized sample (15 hrs) exhibited much larger lamellar correlations. Systematic variations are seen in the data for the 4 hr and 15 hr samples that are due to the anomalous scattering from the ordered Ni atoms in the layered silicates. The erbium study provides the first scattering measurements of heavy metal ion solvation and migration in clays, which has implications for both catalysis and environmental issues. Systematic energy-dependent variations in the signals near the L_{III} edge of Er are observed for the hydrated sample but not for the ''dry'' as-prepared sample.

Grazing-angle characterization of photosynthetic oxygen evolution protein monolayers

Eileen Y. Yu *Biophysics Research Division, University of Michigan, Ann Arbor, MI 48109* James E. Penner-Hahn *Department of Chemistry, University of Michigan, Ann Arbor, MI 48109* Charles F. Yocum *Department of Biology, University of Michigan, Ann Arbor, MI 48109* Robert H. Mayer and Ingrid J. Pickering *Stanford Synchrotron Radiation Laboratory, Stanford, CA 94309* (Presented on 18 October 1995)

Variable-period x-ray standing wave (XSW) spectroscopy has been shown to be a practical probe for studying metalloproteins. The photosynthetic oxygen evolving complex (OEC) is a transmembrane multipolypeptide complex that catalyzes the oxidation of water to dioxygen. The OEC contains Mn, Ca, and Cl and is potentially amenable to study by XSW. In this feasibility study, preliminary results on OEC samples deposited on Au mirrors are discussed. First XSW measurements from the SSRL grazing-incidence setup are presented.

A diamond-window XAFS cell for studies of high-temperature, high-pressure aqueous solutions

John L. Fulton and David M. Pfund *Chemical Sciences Department, Pacific Northwest Laboratory, Richland, WA 99352* Yanjun Ma *Brookhaven National Laboratory, Bldg 510 E, Upton, NY 11973* (Presented on 18 October 1995)

We describe a method to collect x-ray absorption fine structure (XAFS) spectra of ions in a supercritical water solvent. Supercritical water (SCW), at temperatures above water's critical point of 374 °C, is an interesting solvent for chemical reactions and hazard-

ous waste destruction due to the high solubility of organics and the aggressive oxidizing environment. XAFS may provide a better understanding of the solvent environment in SCW. The XAFS cell used in these studies was composed of a block of high-nickel alloy, Hastelloy C-22, containing two windows for transmission of the x-ray beam and a single optical view window. All internal wetted surfaces were platinum plated. The maximum operating conditions for this design were 500 °C and 700 bar. The x-ray transmission windows consisted of CVD (chemical vapor deposition) diamond windows (3 mm diameter $\times$0.5 mm thick) that were brazed to the tip of a standard 1/4-in. high-pressure, coned-shape fitting. Spectra are reported for strontium and rubidium ions in a supercritical water solvent. This cell design could be used for a variety of other solvent systems at high temperatures and high pressures.

A system for single-crystal elastic and inelastic x-ray scattering studies of condensed gases at pressures to 300 MPa and temperatures to 4 K

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A versatile system, operating at pressures to 300 MPa and temperatures to 4 K, has been designed and used for a variety of elastic and inelastic x-ray scattering studies of single crystals of condensed gases. Sintered Be sample cells of volumes 15–30 mm^3 are used. Pressure generation is clean and well controlled. Excellent temperature control allows monitoring of phase transitions associated with solidification and melting. The system has very low background and, combined with the high-intensity of synchrotron radiation, is well suited to studies of low-intensity signals. It has been used for ^{4}He in **q**-dependent studies of fcc lattice dynamics and diffuse scattering and to study thermal defect properties through lattice parameter measurements. In addition, its application to inelastic scattering studies of hcp ^{4}He at 1.5 eV and 10 meV resolution have yielded results about electronic and phonon excitations, respectively. The system can also be used to study other crystalline compounds; in particular, an application has been made to lattice parameter measurements on C_2F_6.

Deconvolution of 3d transition metal L-edge EXAFS and magnetic EXAFS signals

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Due to the closely overlapping L-edge EXAFS regions for the ferromagnetic 3d metals, their analyses have not generally been attempted. Similarly, although analysis of L-edge magnetic EXAFS (MEXAFS) is desirable because of the enhanced amplitude of the signal compared to K-edge MEXAFS, such experiments on the ferromagnetic 3d metals have also not been attempted. In order to address this problem, we describe the use of an iterative Van Cittert deconvolution approach to isolate the LIII-edge from the LII-edge EXAFS and MEXAFS signals for Fe, Co and Ni thin films. The deconvoluted LIII-edge EXAFS data are in agreement with theoretically generated LIII-edge data, thus demonstrating the validity of this approach. Results from the deconvolution of the MEXAFS data also qualitatively agree with previously published MEXAFS data on the same elements at the K-edge. The results for the Fe EXAFS and MEXAFS data will be presented here.

A simple pressure cell and delivery system for the preparation of Xe derivatives for protein crystallography

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We have developed a simple device for preparing Xe derivatives under moderate gaseous pressure (1–100 atm). The device employs a Cajon ultra-torr fitting to ensure a gas-tight seal around a standard x-ray capillary. As such, the cell can accommodate standard x-ray capillaries up to 1.5 mm in diameter without any modification. The device is straightforward to utilize, and samples can be mounted and pressurized in a matter of seconds. In addition, a simple and safe purging and pressurization system has been designed and constructed for the use at beamline 7-1 at the Stanford Synchrotron Radiation Laboratory (SSRL). We describe the construction of both the pressure cell and the delivery system and present results on the cells use in the preparation of xenon derivatives.

Precise lattice location of trace elements within minerals and at their surfaces with x-ray standing waves Y. Qian *Department of Materials Science and Engineering and Materials Research Center, Northwestern University, Evanston, IL 60208* (Presented on 18 October 1995)

Using x-ray standing waves (XSW) generated by dynamical Bragg diffraction, we have precisely measured lattice locations of trace elements within and at the surface of mineral single crystals. Natural calcite samples were cleaved along the (1014) plane to obtain pristine surfaces. After cleavage, some samples were reacted with a dilute aqueous Pb solution to obtain Pb-sorbed surfaces. XSW measurements were then performed on both unreacted and reacted samples using the calcite (1014) Bragg reflection. Results of these XSW measurements show that the naturally occurring trace element M substitutes for C. On the Pb-reacted calcite sample, Pb was located on the calcite (1014) lattice plane where C atoms also reside. Our measurements clearly demonstrate a new and powerful application of synchrotron radiation in earth and environmental sciences to provide element-specific atomic-scale structural information within and at the surface of minerals. The XSW measurements were made at the NSLS X15A and X25 beamlines.

X-ray standing wave study of strain in a buried heterostructure T.L. Lee *Department of Materials Science and Engineering and Materials Research Center, Northwestern University, Evanston, IL 60208* (Presented on 18 October 1995)

The structure of 1 ML InAs on GaAsw (001) capped with 25 Å GaAs was examined by the x-ray standing wave (XSW) method. By monitoring the In L fluorescence while scanning through the GaAs (004) Bragg reflection, the perpendicular strain within the InAs heterolayer was directly measured to be 7.7%, which is in good agreement with the macroscopic elasticity theory (7.3%) and the previously reported local density approximation calculation (7.8%). In this work, we also demonstrated that, combined with the

evanescent-wave emission effect, XSW can be used to measure the strain-induced cap displacement in the growth direction relative to the bulk (004) diffraction plane. This result is consistent with our directly measured strain of the InAs layer. The XSW measurements were performed at the NSLS X15A beamline.

Coherent grating x-ray diffraction (CGXD) and its applications
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We show that an x-ray interference phenomenon, coherent grating x-ray diffraction (CGXD), can be used to study lateral nanostructure arrays on crystal surfaces and interfaces. Compared to Fraunhofer grating diffraction of visible light, x-ray grating diffraction contains information not only about geometric profiles of the surface but also about the internal crystalline structures and lattice strain distributions in the grating features. The grating diffraction pattern can also be measured in a white-beam Laue method using highly collimated polychromatic synchrotron radiation, which provides a parallel data collection scheme and may be useful in *in situ* studies on evolution of nanostructure arrays.

Ultrahigh resolution protein crystallography: Concanavalin A to 0.94 Å and beyond A. M. Deacon, T. Gleichmann, S. J. Harrop, and J. R. Helliwell *Department of Chemistry, University of Manchester, Manchester M13 9PL, England* A. J. Kalb (Gilboa) and J. Yariv *The Weizmann Institute, Israel* (Presented on 18 October 1995)

Many years ago the idea of collecting voluminous quantities of weak reflection intensities from a protein crystal, at high resolution, was a particular challenge [J.R. Helliwell (1979) Daresbury Study Weekend DL/SCI R13, pp. 1–6]. The combination of insertion devices with very high x-ray fluxes at short x-ray wavelengths, sensitive CCD detectors, and freezing of crystals have provided the means to certainly match those best hopes. So much so that the data can best be described as ultrahigh resolution, at least as evidenced in our studies of the 25000 molecular weight plant protein concanavalin A. (The intrinsic property of this protein is to bind sugar molecules; it is implicated in cell-to-cell recognition processes and is widely used as a laboratory diagnostic tool.) At CHESS we have used a 0.9 Å wavelength beam on station A1, fed by a 24 pole multipole wiggler. Both an imaging plate system and the Princeton 1k CCD detector [M. Tate *et al.*, J. Appl. Cryst. **28**, 196 (1995)] have been used on this experimental setup to collect diffraction data sets from frozen concanavalin A crystals (saccharide-free crystal form). The rapid readout of the CCD was most convenient compared with the image plate and its associated scanning and erasing. Moreover the data processing results towards the edges of the detectors, 0.98 Å, show that the CCD is much better than the image plate at recording these weaker data (Rmerge(I) 13% versus 44%, respectively). The poor performance of the image plate with weak signals has of course been documented by the Daresbury detector group [R. Lewis, J. Synchrotron Radiation **1**, 43 (1994)]. However, the aperture of the CCD used was limiting here. Very recently, in another run at CHESS with the CCD on A1, we have been able to record diffraction data to 0.94 Å by further offsetting the detector. We again found that the reflections are still strong at the edge. Clearly the use of even shorter wavelengths than 0.9 Å would be very useful in matching the solid angle of the diffraction pattern to the available detector aperture, for a reasonable crystal-to-detector distance. In addition, absorption errors in the data can be simultaneously removed by such a strategy. Indeed, finely focused x-ray beams of, say 0.5 Å wavelength, are especially well suited to high energy, low emittance synchrotron radition (SR) machines. Some initial tests carried out on CHESS station F2 with a 0.5 Å wavelength beam and the CCD detector show an improvement in the R-merge(I) to 2 Å resolution, in comparison to the data collected at 0.9 Å wavelength (i.e., 2.3% versus 3.0%). In conclusion, the diffraction resolution limit (0.94 Å) seen already in our concanavalin A studies can be further enhanced and is important for the most detailed molecular model refinement (and the testing of structure solving strategies), in conjunction with novel spectroscopic and theoretical studies. This paper builds upon the work of Deacon *et al.* [Rev. Sci. Instrum. **66**, 1287 (1995)].

Possible use of direct silicon-on-silicon bonding for construction of analyzers for inelastic scattering
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Bonding of silicon directly to silicon is possible with proper preparation of the two surfaces to be bonded. The advantage of such a method is that a bonding agent is not required, and direct bonding avoids figure errors introduced by thickness variations in a bonding agent. We have succeeded in bonding a 3-inch-diameter diced (1 mm × 1 mm) silicon(111) oriented wafer to a silicon concave spherical form having a 3-m radius. A very good rms figure error of 0.059 millirad over the entire area of the analyzer was measured. The suitability for x-ray inelastic scattering due to introduced strain is, however, still an open question. Whether or not deleterious strain is unavoidably introduced during the bonding process is a question we will answer with availability of photons on sector 3 of the SRI CAT at the Advanced Photon Source.

Bent crystal analyzer without grooves for inelastic x-ray scattering
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A new design of analyzers for inelastic x-ray scattering is proposed. In the usual design, special measures are taken to avoid the influence of bending strains on the resolution. The novel design suggests keeping the backscattering geometry but using reflecting planes that are not parallel to the crystal surface in conjunction with nonspherical bending. Conditions can be ensured in order that a) the bending strains not affect the x-ray diffraction, and b) the radiation emitted by a point sample is focused back to a point detector. Examples of configurations satisfying those conditions are given for Si and Ge crystals.

Performance of the beam position monitor for the Advanced Photon Source
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Performance measurement and analysis of the Advanced Photon Source (APS) beam position monitor (BPM) electronics are reported. The results indicate a BPM resolution of 0.16 μm·mA/$\sqrt{\text{Hz}}$ in terms of the single-bunch current and BPM bandwidth. For the miniature insertion device (ID) BPM, the result was 0.1 μm·mA/$\sqrt{\text{Hz}}$. The improvement is due to the 3.6 times higher position sensitivity (in the vertical plane), which is partially canceled by the lower button signal by a factor of 2.3. The minimum single-bunch current required was roughly 0.03 mA. The long-term drift of the BPM electronics independent of the actual beam motion has measured at 2 μm/hr, which settled after approximately 1.5 hours. This drift can be attributed mainly to the temperature effect. Implications of the BPM resolution limit on the global and local orbit feedback systems for the APS storage ring will also be discussed.

BESSY Bragg-Fresnel multilayer beam monitors

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X-ray optical systems based on Bragg-Fresnel multilayer components imaging an electron beam in a storage ring with μm resolution are presented. Design concepts are compared to alternative methods, and the aberrations and limits of Bragg-Fresnel multilayer optics are discussed. Experimental results of imaging the BESSY I source with sub-10-μm resolution are presented, and the development of a compact Bragg-Fresnel multilayer telescope as a BESSY II standard beam monitor is described.

On the discrimination of dipole background from four blade photon BPMs for insertion devices

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The position response of blade monitors is mainly determined by their spectral sensitivity for low energy photoelectrons. For insertion devices with high energy first harmonics, the signals are contaminated by the light from the upstream and downstream bending magnets. A blade monitor design using energy selective detection of the photoelectrons from the blades will be presented. This way the background signals from the dipoles can be supressed and only position information from the insertion device beam can be obtained. A simulation code and experimental results at BESSY I will be presented.

System for monitoring position of the photon beam in the new undulator beamline at SRC

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A system of beam position monitors was developed for the plane grating monochromator (PGM) undulator beamline at the Synchrotron Radiation Center (SRC). Two monitors are located in the upstream section of the beamline providing the capability of measuring the transverse angular and spatial motion of the photon beam. The jaws of the entrance slit of the monochromator may also be used as monitors to detect changes in the vertical position of the source. Overall, the system allows measurements of the photon beam position and angle to be done with ~10 μm and ~3 μrad accuracy, respectively. The aperture of the monitors can be changed in both the vertical and horizontal direction. Thus, the beam motion can be measured with the highest possible resolution for any value of the undulator deflection parameter K. In addition, the design of the monitors provides the capability of mapping the angular power distribution of the photon beam. The first monitor was installed and successfully tested. The design of the system and results of test measurements are reported.

Beam position monitor for the SPring-8 synchrotron

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Beam position monitors (BPMs) for the SPring-8 synchrotron have already been designed and manufactured. Each BPM pickup has four button-type electrodes, and the output signals from the electrodes are switched by fast PIN-diode and are measured by signal detection systems. Eighty BPMs and four detection systems are placed around the synchrotron. Calibration of beam position of the 80 BPMs was finished successfully. In this paper, we present the structure of the BPM pickup, the electronics of the signal detection system, and the calibration system.

Smart x-ray beam position monitor system for the Advanced Photon Source

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In third-generation synchrotron radiation sources, such as the Advanced Photon Source (APS), the sensitivity and reliability requirements for the x-ray beam position monitors (XBPMs) are much higher than for earlier systems. Noise and contamination signals caused by radiation emitted from the bending magnet become a major problem. The regular XBPM calibration process can only provide signal correction for one set of conditions for the insertion devices (ID). During normal operation, parameters affecting the ID-emitted beam, such as the gap of the ID magnets and the beam current, are the variables. A new smart x-ray beam position monitor system (SBPM) has been conceived and designed for the APS. It has a built in self-learning structure with EEPROM memory that is large enough to ''remember'' a complete set of calibration data covering all the possible operating conditions. During the self-learning mode, the monitor system initializes a series of automatic scan motions with information for different ID setups and records them into the database array. During normal operation, the SBPM corrects the normalized output according to the ID setup information and the calibration database. So that, with this novel system, the SBPM is always calibrating itself with the changing ID set up conditions.

Initial time-resolved particle beam profile measurements at the Advanced Photon Source

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The commissioning of the 7-GeV Advanced Photon Source (APS) storage ring began in early 1995. Characterization of the stored particle beam properties involved time-resolved transverse and longitudinal profile measurements using optical synchrotron radiation (OSR) monitors. Early results include the observation of the beam on a single turn, measurements of the transverse beam sizes after damping using a 100 μs integration time ($\sigma_x \sim 150 \pm 25$ μm, $\sigma_y \sim 65 \pm 25$ μm, depending on vertical coupling), and measurement of the bunch length ($\sigma_\tau \sim 25$ to 55 ps, depending on the charge per bunch). The results are consistent with specifications and predictions based on the 8.2 nm-rad natural emittance, the calculated lattice parameters, and vertical coupling less than 10%. The novel, single-element focusing mirror for the photon transport line and the dual-sweep streak camera techniques, which allow turn-by-turn measurements, will also be presented. The latter measurements are believed to be the first of their kind on a storage ring in the USA.

Design and performance of the ALS diagnostic beamline

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The design and operation of an imaging beamline at the Advanced Light Source used for providing diagnostic information on the electron beam for the accelerator and experimental groups is described. This system is based on a Kirkpatrick-Baez mirror pair and utilizes a carbon filter to give a bandpass in the soft x-ray region. The focused x-rays are viewed on a single-crystal scintillator through an optical microscope and the image recorded on a CCD camera. This system, together with other instruments to evaluate beam size, stability, and other time-dependent information, is described, data are presented, and the operation of the overall beamline is evaluated.

Beam size measurement of the stored electron beam at the APS storage ring using pinhole optics

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Beam sizes of the stored electron beam at the APS storage ring were measured using pinhole optics and bending magnet x-rays in single-bunch and low-current mode. A white-beam pinhole of 25 μm and a fast x-ray imaging system were located 23.8 m and 35.4 m from the source, respectively. The x-ray imaging system consists of a $CdWO_4$ scintillation crystal 60 μm thick, an optical imaging system, and a CCD detector. A measurement time of a few tenths of a second was obtained on a photon beam of $E>30$ keV produced from a 7-GeV electron beam of 2-mA current. The resolution of the pinhole imaging system was evaluated to be 16 μm. The measured vertical and horizontal sizes of the electron beam were in reasonable agreement with the expected values.

Signal processing, data acquisition, and initial commissioning results of the APS storage ring vertical beam missteering wire monitor

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Two wire monitors have been developed and installed in the Advanced Photon Source (APS) storage ring insertion device (ID) front ends to directly detect synchrotron radiation exiting the storage ring vacuum chamber that is missteered by ± 5 mm. Each wire monitor employs four in-vacuum tungsten wires positioned above and below the normal x-ray orbit. The temperature change of the wire under x-ray irradiation causes a resistance change that is detected by a local high-sensitivity low-noise signal processing electronics unit with four independent channels. The four outputs of the local unit are linked to a central VME wire resistance measurement and interlock module via 4–20 mA current loops. The central VME module can accept inputs from up to eight wire monitors and has a heartbeat that feeds a MPS summation module. In this paper, an overview of the wire monitor signal processing and data acquisition system design is presented together with recent commissioning results.

Measurement of the absolute energy and energy spread of the ESRF electron beam using undulator radiation

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Two simple methods of characterizing the average energy and energy spread of the electron beam have been developed at the ESRF. Both are based on analysis of the x-ray spectrum from an undulator. The first allows the absolute energy of the electrons to be determined. It is based on the dependence between the harmonics wavelengths and the electron beam energy. The x-ray beam is monochromatized at 21 keV by a silicon crystal in backscattering geometry. By adjusting the magnetic gap, one makes the third harmonic of the radiation from an undulator coincide with the energy selected by the crystal. The main errors come from the uncertainties in the undulator's magnetic field and period. By operating the undulator at low field ($K=0.36$), an absolute accuracy of 10^{-3} is reached for the electron energy. The energy spread measurement is performed by analyzing the broadening of the harmonics' profile. It is deduced from the measured ratio between the height of the peak of the seventh harmonic at 29 keV and the height of a secondary maximum at lower energy. The measured low current energy spread is $1.1 \times 10^{-3} \pm 20\%$. It increases with the single bunch current due to turbulent bunch widening.

3-D x-ray mirror metrology with a vertical scanning long trace profiler

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The long trace profiler (LTP) was originally developed at Brookhaven National Laboratory for the specific purpose of measuring the surface figure of large cylindrical mirrors used at grazing incidence in synchrotron radiation (SR) beamlines. In its original configuration, it could measure only along one line down the center of the cylinder. A single linear profile is often sufficient to gauge the quality of the optical surface on these kinds of mirrors. For some applications it is necessary to measure the topography of the entire surface, not just along one line but over a grid that covers the entire surface area. We have modified a standard LTP to enable measurement of the complete surface of Wolter telescope optics in a vertical configuration. The vertical scanning LTP (VSLTP) is capable of producing a complete 3-D map of the surface topography errors

relative to the ideal desired surface on complete segments of paraboloids and hyperboloids. The instrument uses a penta prism assembly to scan the probe beam in the longitudinal direction parallel to the mirror symmetry axis and uses a precision rotary stage to provide scans in the azimuthal direction. A Risley prism pair and a dove prism are used to orient the probe beam in the proper direction for the azimuthal scans. The repeatability of the prototype instrument is better than 20 nm over trace lengths of 35 mm with a slope measurement accuracy of about 1 microradian.

In-situ long trace profiler for measurement of mirror profiles at third-generation synchrotron facilities

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X-ray mirrors have the potential to be subjected to extremely high heat loads at third-generation synchrotron radiation sources. In many cases, sophisticated cooling methods will be required to prevent surface distortion that would otherwise degrade the intrinsic source brightness. As a diagnostic for such mirrors, we have previously proposed to modify the long trace optical profiler for use within a UHV mirror chamber [Shinan Qian *et al.*, Optical Engineering **34**, 396 (1995)], thereby making it feasible to take profile measurements of mirrors irradiated with high power x-ray beams. We present in detail the mechanical design of a complete *in-situ* measurement. The objective of developing an *in-situ* measurement system is to aid the development of reliable, low-cost, high-heat-load substrates for mirrors and multilayers. This will provide a firm basis on which to design new optical elements that will be necessary as a result of performance enhancements to current machines, as well as future generations of storage rings.

The APS optics topography station

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An in-house station for topographic testing of x-ray optical elements for the Advanced Photon Source experimental beamlines was set up by the Experimental Facilities Division of Argonne National Laboratory. A new double-crystal x-ray diffractometer was designed and built keeping in mind the need for testing large crystals possibly attached to cooling manifolds and lines. A short description of the new facility is given. The instrument performance fully satisfies imposed requirements, and the machine was successfully used for testing several silicon and diamond crystals.

The Advanced Photon Source Metrology Laboratory

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The Advanced Photon Source (APS) Metrology Laboratory is now operational in its permanent location in a cleanroom environment on the Experiment Hall floor of the APS site. The Metrology Laboratory will provide characterization of the figure and finish of x-ray optical surfaces for the user community using visible light instrumentation. Three noncontact instruments are now available for measuring surface features with lateral resolution from less than a micron to lengths of 2 meters and with a vertical resolution as small as an Angstrom. This paper gives a brief description of the three instruments used to cover this spatial frequency range and other associated issues, such as the environment and cleanliness of the laboratory.

Beamline diagnostics for protein crystallography using synchrotron radiation

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Beam diagnostics devices are described for the monitoring of all basic parameters relevant to protein data collection using synchrotron radiation. The parameters include the total power in the white beam, the positions and directions of the incident white and monochromatic beams, and the intensity, wavelength, and polarization in the incident monochromatic beam. Such devices have been installed on a doubly focusing wiggler beamline, BW6, at DORIS. They assure high quality in protein data collection despite fluctuations in the beam, facilitate rapid alignment of the entire beamline, and provide a basis for automatic realignment of the diffraction setup and the x-ray optics.

Beamline control and data acquisition software

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An international collaboration of software developers has been working for several years to advance the state of the art of control systems and has produced software and development methods that are directly applicable to synchrotron radiation (SR) instrumentation. The software is collectively entitled EPICS and is essentially an extensible tool kit for implementing distributed control systems. The EPICS collaboration now includes developers representing many of the Advanced Photon Source (APS) beamlines, as well as developers from the Stanford Synchrotron Radiation Laboratory, the Advanced Light Source, and the Gemini and Keck telescopes. As part of this collaboration, we have developed software tools for controlling and acquiring data from SR beamlines and combined them with tools developed by others to support laboratories and experiments at the APS and other SR facilities. Applications of EPICS-based software in SR instrumentation will be described, some consequences of collaborative development will be discussed, and the intended impact of this software on the science conducted at SR facilities will be discussed.

XSCAN x-ray data acquisition and analysis software for the MATRIX X-18A x-ray scattering beamline at the NSLS

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A versatile and easy-to-use computer software package has been developed for equipment control, data acquisition and analysis at the MATRIX X-18A x-ray scattering beamline at the National Synchrotron Light Source. The software runs on any IBM-compatible

personal computer running under MS-DOS and makes use of the GPIB and AT-Bus interfaces. The menu-driven program is user friendly for a wide range of x-ray experiments through control of all aspects of the x-ray beamline. Equipment interfaces include counter-timer, stepping motor controllers, multichannel analyzer, and temperature controller. Real space and reciprocal space scans are possible, as well as an external file scan, which allows control of up to six diffractometer motions plus the energy simultaneously. Orientation matrix calculations, peak fitting routines, and an extensive help file system are included. Plans are presently underway to upgrade the software to run under Windows NT.

Modular data acquisition system and its use in gas-filled detector readout at ESRF

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Since 1992, 18 ESRF beamlines are open to users. Although the data acquisition requirements vary a lot from one beamline to another, we are trying to implement a modular data acquisition system architecture that would fit with the maximum number of acquisition projects at ESRF. Common to all of these systems are large acquisition memories and the requirement to visualize the data during an acquisition run and to transfer them quickly after the run to safe storage. We developed a general memory API handling the acquisition memory and its organization and another library that provides calls for transferring the data over TCP/IP sockets. Interesting utility programs using these libraries are the 'online display' program and the 'data transfer' program. The data transfer program as well as an acquisition control program rely on our well-established 'device server model', which was originally designed for the machine control system and then successfully reused in beamline control systems. In the second half of this paper, the acquisition system for a 2D gas-filled detector is presented, which is one of the first concrete examples using the proposed modular data acquisition architecture.

Argonne National Laboratory high performance network support of APS experiments

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Argonne National Laboratory is currently positioned to provide access to high performance regional and national networks. Much of the impetus for this effort is the anticipated needs of the upcoming experimental program at the APS. Some APS collaborative access teams (CATs) are already pressing for network speed improvements and security enhancements. Requirements range from the need for high data rate, secure transmission of experimental data, to the desire to establish a ''virtual experimental environment'' at their home institution. In the near future, 155 megabit/sec (Mb/s) national and regional asynchronous transfer mode (ATM) networks will be operational and available to APS users. Full-video teleconferencing, virtual presence operation of experiments, and high speed, secure transmission of data are being tested and, in some cases, will be operational. We expect these efforts to enable a substantial improvement in the speed of processing experimental results as well as an increase in convenience to the APS experimentalist.

Personnel Safety System for the beamlines at the Advanced Photon Source

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The Personnel Safety System (PSS) at the Advanced Photon Source is a high reliability, fail-safe, redundant, engineered safety system that provides personnel access control to prevent inadvertent entry into experimental stations when hazardous radiation conditions exist and warns personnel of changes in safe operating conditions inside these stations. Single fault tolerant access control is provided by two independent interlock ''chains'' implemented via programmable logic controllers (PLCs). Reduction of common mode failures is accomplished by different hardware and software platforms for the two chains. The system design is presented.

Front-end equipment protection system at the Advanced Photon Source

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The front-end Equipment Protection System (FE-EPS) at the Advanced Photon Source (APS) is a high reliability, fail-safe single-chain interlock and control system. It consists of an Allen-Bradley PLC-5/30 processor, local and remote I/O racks, monitoring and control panels, serial communication links, and field devices. Each front end is equipped with a dedicated EPS. The system monitors a variety of sensors (e.g., vacuum, cooling water, temperature, pneumatic pressure), and controls front-end (FE) photon shutters and UHV valves. The main functions of the FE-EPS are to guard the integrity of the storage ring vacuum against vacuum excursions in the FE and beam transport line, as well as to protect the front-end and beamline components from being damaged by synchrotron radiation. The FE-EPS interfaces to six other APS interlock and control systems. Information about FE interlocks and devices is displayed on UNIX machines using the EPICS software tool kit. The system design is presented.

Design criteria for beamline protection systems at the Advanced Photon Source

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Designing and building beamlines at third-generation sources force beamline designers to place a high emphasis on the beamline equipment protection system (EPS). This work presents a set of design criteria as well as a prototype system that UNI-CAT and DND-CAT will use for the basis of their EPSs at the Advanced Photon Source. These criteria balance hardware and manpower costs in the design as well as the reusability of already existing software protocols (e.g., World Wide Web and EPICS) to report conditions to the beamline staff.

Designing a Beamline Equipment Protection System Using a Programmable Logic Controller

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As part of the Synchrotron Radiation Instrumentation Collaborative Access Team (SRI-CAT), a new beamline equipment protection system was designed, implemented and installed. The beamline equipment protection system is designed to assure the safe operation of bending magnet and insertion device beamline components, such as white-beam slits, user filters, shutters and stops, mirrors and monochromators. Design goals of the equipment protection system were to improve equipment safety performance, reduce nuisance trips and incorporate additional system functions with minimal cost. To meet the requirements of such a safety system, it was configured to use a programmable controller, remote block input/output (I/O), local interfaces and a serial communication link known as remote I/O (RIO). Aspects about the design requirements, functionality and constraints are presented, as well as specifics on programmable ladder logic design, hardware selection, testing and interfacing requirements.

A review of methods for experimentally determining linear optics in storage rings

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In order to maximize the brightness and provide sufficient dynamic aperture in synchrotron radiation storage rings, one must understand and control the linear optics. Control of the horizontal beta function and dispersion is important for minimizing the horizontal beam size. Control of the skew gradient distribution is important for minimizing the vertical size. In this paper, various methods for experimentally determining the optics in a storage ring will be reviewed. Recent work at the National Synchrotron Light Source X-Ray Ring will be presented, as well as work done at laboratories worldwide.

Investigation of low-frequency beam motion at the Advanced Photon Source

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The storage ring of the Advanced Photon Source has relatively tight tolerance requirements for beam stability. The tolerances of the rms beam motion in the insertion device straight sections are set to be less than 4.4 μm and 17 μm in the vertical and horizontal planes, respectively, in a bandwidth of 4–50 Hz. Sources of beam motions have been investigated for mechanical vibrations of the magnets and vacuum chambers induced by ground motion and water systems and for power supply ripple. Horizontal beam motions in a bandwidth of 9–12 Hz have been significantly reduced by inserting viscoelastic damping pads between the girder supports and pedestals, and by welding the magnet cooling headers to the ceiling of the storage ring tunnel. Current ripple of S1A sextupoles has been identified as a source of beam motion in a bandwidth of 5–8 Hz. The eddy current induced by the ripple field in the sextupole produced a vertical dipole field to drive the beam horizontally. After modification of the sextupole power supplies, the beam stability requirements have now been met even without activating the feedback system.

Digital closed orbit feedback system for the Advanced Photon Source storage ring

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Closed orbit feedback for the Advanced Photon Source (APS) storage ring employs unified global and local feedback systems for stabilization of particle and photon beams based on digital signal processing. Hardware and software aspects of the system will be described. In particular, we will discuss global and local orbit feedback algorithms, PID (proportional, integral, and derivative) control algorithm, application of digital signal processing to compensate for vacuum chamber eddy current effects, resolution of the interaction between global and local systems through decoupling, self-correction of the local bump closure error, user interface through the APS control system, and system performance in the frequency and time domains. The system hardware, including the digital signal processor (DSPs), is distributed in 20 VME crates around the ring, and the entire feedback system runs synchronously at 4-kHz sampling frequency in order to achieve a correction bandwidth exceeding 100 Hz. The required data sharing between the global and local feedback systems is facilitated via the use of fiber-optically networked reflective memories.

Digital x-ray processing electronics for fluorescence EXAFS and spectroscopy

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We have developed a digital x-ray processor (DXP) for x-ray fluorescence spectroscopy, implemented in a 4-channel CAMAC module, which accepts inputs of either polarity from reset or tail preamplifiers, and outputs one spectrum per channel. Digital trapezoidal shaping and efficient pileup rejection are implemented in dedicated logic, with programmable peaking times from 0.5 to 20 msec. The energy resolution is comparable to good analog units at equivalent peaking times. A maximum input count rate (ICR) of 500,000 cps per channel can be accomodated at a peaking time of 0.5 msec. A digital signal processor on each channel is used to collect the data, apply corrections, and update the spectrum. The capabilities of the DXP prototype at high rates was tested at SSRL. Using an Ortec single-element germanium detector, the resolution was seen to degrade somewhat with increasing ICR above 150,000 cps, due to effects that we are still investigating. Collaborating with Hewlett-Packard and SSRL, the DXP was also used with a Kevex Si(Li) detector for trace element detection on silicon wafers in comparison with Kevex readout electronics. At 4 msec peaking time, DXP's resolution was slightly worse (10–15 eV) due to some excess noise pickup, though the background levels in the spectra were essentially identical in the two systems and the DXP's maximum count rate was several times higher.

Status and projected performance of the Duke FEL lab soft x-ray source

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Previous magnetic field measurements on the entrance half of the NIST undulator showed errors that resulted in a beam path deflec-

tion of 5.2 mm [Wallace *et al.*, Nucl. Instrum. Methods A **331**, 759 (1993)]. Pole height variations as much as .009'' gave rise to field errors of up to 2% at a gap of 20 mm. We report on our effort to rebuild the NIST undulator through a series of *in-situ* and off-line measurements and modifications. Initial results indicate that at 40 Å, a brightness of 2.5×10^{18} (ph/sec/mm^2/mrad^2/A/0.1% BW) can be achieved. Commissioning of the undulator will take place in January 1996.

An elliptical wiggler beamline for the ALS

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A beamline for circularly polarized radiation produced by an elliptical wiggler has been designed at the ALS covering the broad energy range from 50 eV to 2000 eV. The rigorous theory of grating diffraction efficiency has been used to maximize transmitted flux. The nature of the elliptical wiggler insertion device creates a challenging optical problem due to the large source size in the vertical and horizontal directions. The requirement of high resolving power combined with the broad tuning range and high heat loads complicate the design. These problems have been solved by using cooled optics and a variable-included angle monochromator of the ''constant length'' type with high demagnification onto its entrance slit.

Elliptically polarizing undulator beamlines at the Advanced Light Source

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Circular polarization insertion devices and beamlines at the Advanced Light Source are described. The facility will consist of multiple undulators feeding two independent beamlines, one optimized for microscopy and the other for spectroscopy. The energy range of the beamlines will go from below 100 eV to 1800 eV, enabling studies of the magnetically important $L_{2,3}$ edges of transition metals and the $M_{4,5}$ edges of rare earths.

High-resolution beamline 9.3.2 in the energy range 30–1500 eV at the Advanced Light Source: Design and performance

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Bending magnet beamline 9.3.2 at the Advanced Light Source (ALS) was designed for high resolution spectroscopy with the capability for delivering circularly polarized light in the soft x-ray energy region using three gratings. The monochromator is a fixed included-angle spherical grating monochromator (SGM) and was originally used at SSRL as a prototype for later insertion-device-based monochromators for the ALS. For operation at the ALS, the toroidal pre-mirror used at SSRL was replaced by a horizontally focusing and a vertically focusing mirror in the Kirkpatrick-Baez configuration. Circularly polarized radiation is obtained by inserting a water-cooled movable aperture in front of the vertically focusing mirror to allow selecting the beam either above or below the horizontal plane. To maintain a stable beam intensity through the entrance slit, the photocurrent signals from the upper and lower jaws of the entrance slit are utilized to set a feedback loop with the vertically deflecting mirror piezoelectric drive. The beamline end station has a movable platform that accommodates two experimental chambers enabling the synchrotron radiation to be directed to either one of the two experimental chambers without breaking the vacuum.

Calibration and standards beamline 6.3.2 at the Advanced Light Source

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This bending magnet beamline has been in operation since February 1995 for the characterization of optical elements (mirrors, gratings, multilayers, detectors, etc.) in the energy range 50–1000 eV. Although it was designed primarily for precision reflectometry of multilayer reflecting optics for EUV projection lithography, it has capabilities for a wide range of measurements. The optics consist of a monochromator, a reflectometer, and refocusing mirrors to provide a small spot on the sample. The monochromator is a very compact, entrance-slitless, varied-line-spacing plane-grating design in which the mechanically ruled grating operates in the converging light from a spherical mirror working at high demagnification. Aberrations of the mirror are corrected by the line spacing variation, so that the spectral resolving power $\lambda/\Delta\lambda$ is limited by the ALS source size to about 7000. Wavelength is scanned by simple rotation of the grating with a fixed exit slit. The reflectometer has the capability of positioning the sample to within 10 μm and setting its angular position to 0.002°. LABVIEW™ based software provides a convenient interface to the user. The reflectometer is separated from the beamline by a differential pump and can be pumped down in 1/2 hour. Auxiliary experimental stations can be mounted behind the reflectometer. Results are shown that demonstrate the performance and operational convenience of the beamline

A beamline for 1–4 keV microscopy and coherence experiments at the Advanced Photon Source

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The third-generation Advanced Photon Source will open up dramatic new opportunities for experiments requiring coherent x-rays, such as scanning x-ray microscopy, interferometry, and coherent scattering. We are building a beamline at the Advanced Photon Source to exploit the potential of coherent x-ray applications in the 1–4 keV energy region. A high brightness 5.5-cm-period undulator supplies the coherent x-rays. The beamline uses horizontally deflecting grazing-incidence optical elements to preserve the coherence of the undulator beam. The optics have multilayer coatings for operation at energies above 1.5 keV. This paper discusses the beamline design and its expected performance.

Design of a dedicated beamline for x-ray microfocusing- and coherence-based techniques at the Advanced Photon Source
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A dedicated insertion-device beamline has been designed and is being constructed at the Advanced Photon Source (APS) for development of x-ray microfocusing- and coherence-based techniques and applications. Important parameters considered in this design include preservation of source brilliance and coherence, selectable transverse coherence length and energy bandwidth, high beam angular stability, high order harmonic suppression, quick x-ray energy scan, and accurate and stable x-ray energy. The overall design of this beamline layout and the major beamline components are described. The use of a horizontally deflecting mirror as the first optical component is one of the main features of this beamline design, and the resulting advantages are briefly discussed.

Earth, soil and environmental science research facility at sector 13 of the Advanced Photon Source. I. Sector layout and optical design Peter Eng, Yifei R. Jaski, Nancy Lazarz, Paul Murray, Joseph Pluth, Harvey Rarback, Mark Rivers, and Stephen Sutton *CARS, University of Chicago, 5640 S. Ellis Avenue, Chicago, IL* (Presented on 20 October 1995)

The earth, soil and environmental science component (GSECARS) of the Consortium of Advanced Radiation Sources (CARS), is designing a national research facility to be built at sector 13 of the Advanced Photon Source. The bending magnet beam will be split to allow simultaneous operation of two stations, a monochromatic (8–15 keV) side station and a multipurpose, white beam/monochromatic end station. The undulator beamline will have two white beam stations, which may operate simultaneously using a double-crystal monochromator (cryogenic Si) with a thin first crystal. In this mode, the upstream station will accept the monochromatized (4.5–22 keV) beam deflected horizontally by a third (bendable) Ge crystal, while the end station accepts the high energy component (blue beam) transmitted by the first crystal. The need for small x-ray beams and broad spectral range have led us to base the focusing aspects of the optic design on grazing incidence mirrors. Both our bending magnet and insertion device beamlines will have long ($\sim$1 m), bendable mirrors (demagnification $<$11, E(cut-off) $>$70 keV; beam sizes $>$tens of micrometers). For smaller focal spots, we will use small, dynamically bent Kirpatrick-Baez mirrors (demagnification 100–400; E(cut-off) $<$70 keV; beam sizes $\sim$1 micrometer). A unique aspect of our insertion device beamline is the ability to deliver focused white beam to the sample, through the incorporation of a power management pinhole in the first optics enclosure.

Earth, soil and environmental science research facility at sector 13 of the Advanced Photon Source. II. Scientific program and experimental instrumentation S. Sutton, P. J. Eng. Y. R. Jaski, N. Lazaraz, J. Pluth, P. Murray, H. Rarback, and M. Rivers *CARS, 5640 S. Ellis Avenue, University of Chicago, Chicago, IL* (Presented on 20 October 1995)

The GSECARS (APS sector 13) scientific program will provide fundamental new information on the deep structure and composition of the Earth and other planets, the formation of economic mineral deposits, the cycles and fate of toxic metals in the environment, and the mechanisms of nutrient uptake and disease in plants. In the four experimental stations (2 per beamline), scientists will have access to three main x-ray techniques: diffraction (microcrystal, powder, diamond anvil cell, and large volume press), fluorescence microprobe, and spectroscopy (conventional, microbeam, liquid and solid surfaces). The high pressure facilities will be capable of x-ray crystallography at P$>$360 GPa and T$\sim$6000 K with the diamond anvil cell and P$\sim$25 GPa and T$\sim$2500 °C with the large volume press. Diffractometers will allow study of 1 micrometer crystals and micro-powders. The microprobe (1 micrometer focused beam) will be capable of chemical analyses in the sub-ppm range using wavelength and energy dispersive detectors. Spectroscopy instrumentation will be available for XANES and EXAFS with microbeams as well as high sensitivity conventional XAS and studies of liquid and solid interfaces. Visiting scientists will be able to setup, calibrate, and test experiments in off-line laboratories with equipment such as micromanipulators, optical microscopes, clean bench, glove boxes, high powered optical and Raman spectrometers.

Design of the Structural Biology Center beamlines at the APS Gerd Rosenbaum and Edwin M. Westrbrook *Argonne National Laboratory, 9700 S. Cass Ave., Argonne, IL 60439* (Presented on 20 October 1995)

The Structural Biology Center-CAT will develop and operate a sector of the APS as a user facility for studies in macromolecular crystallography. The techniques applied will include multiple-energy anomalous dispersion (MAD) phasing and polychromatic (Laue) data collection. Data will be recorded on a high resolution CCD-area detector. The SBC is constructing two beamlines, one for radiation from an undulator and one for radiation from a bending magnet. The x ray optics of both beamlines are designed to produce a highly demagnified image of the source in order to match the focal size with the sizes of the sample and the resolution element of the detector. Vertical focusing is achieved by a flat, cylindrically bent mirror. Horizontal focusing is achieved by sagittally bending the second crystal of a double crystal-monochromator. The double-crystal monochromators of both beamlines have a constant exit height output beam. On the undulator beamline, two double-crystal monochromators are installed in series—one with Si-111 crystals and the second with Si-220 crystals—in order to facilitate quick change between high flux and narrow bandwidth. For the heat-loaded first crystals, the liquid-nitrogen-cooled, thin-web design being developed by the APS has been adopted. On the bending magnet beamline, three crystals (Si-111, Si-220, Si-400) are mounted side-by-side on the first crystal stage and translated into the beam is required.

The PNC-CAT insertion device beamline at the Advanced Photon Source
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The PNC-CAT is a consortium of Pacific Northwest institutions formed to instrument a sector (number 20) at the Advanced Photon Source (APS). Research is planned in a variety of areas, with an emphasis on environmentally based problems. The insertion device beamline is based on the APS undulator A and will be optimized for producing microbeams as well as for applications requiring energy scanning capabilities. This paper describes the basic layout and

some special features of the beamline. Two experimental stations are planned: one general purpose and one dedicated to MBE and surface science problems. Both tapered capillaries and Kirkpatrick-Baez optics will be used for producing microbeams, and a large optical bench is planned for the main station to allow for easy accommodation of new optics developments. Design calculations and initial capillary tests indicate that flux densities exceeding 10^{11} photons/sec/mm^2 should be achievable. All major components are under construction or in procurement, and initial testing is planned for late 1996.

SINBAD: A synchrotron infrared beamline at DAFNE

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Different optical layouts for a beamline that extracts infrared synchrotron radiation from a bending magnet are discussed, and their performances are compared by use of ray-tracing simulations. Specific results are presented for SINBAD, the beamline to be mounted on the new Frascati collider DAΦNE.

TGM-to-SGM conversion at NSLS beamline U7A: Recyclying of beamline components

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The U7A bending magnet toroidal grating monochromator (TGM) beamline has been converted into a spherical grating monochromator (SGM) type, without constructing any new vacuum components. That is, the mirror, slit, and grating chambers have been recycled. The inherited optical arrangement and the recycling concept prevented the use of ''standard'' SGM Kirkpatrick-Baez collecting and focusing mirrors at the front end. We show that this modification is not a serious detriment to the optical properties of the resulting beamline. Specifically, the resolution is completely unaffected and the throughput is approximately 2/3 of the ''standard'' SGM value. The flux and photon energy resolution of the U7A beamline throughout its 200–1000 eV operating photon energy range will be presented. Three end stations are being constructed for this beamline, featuring soft x-ray absorption and photoemission chambers optimized for operation in the carbon K-, oxygen K-, and transition metal L-edge ranges. Two of these end stations will be preceded by refocusing mirrors that will focus the soft x-rays to <1 mm spot size onto their samples.

First results from the high brightness x-ray spectroscopy beamline 9.3.1 at ALS

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Beamline 9.3.1 at the Advanced Light Source (ALS) is a windowless beamline, covering the 1–6 keV photon energy range. This beamline is designed to achieve the goal of high brightness at the sample for use in the x-ray atomic and molecular spectroscopy (XAMS) science, surface and interface science, biology and x-ray optical development programs at ALS. X-ray absorption and time-of-flight photoemission measurements in 2–5 keV photon energy range along with the flux, resolution, spot size and stability of the beamline will be discussed. Prospects for future XAMS measurements will also be presented.

Passive vibration damping of the APS machine components

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The accelerator and beamline components of the Advanced Photon Source have stringent vibration criteria in order to meet the beam stability requirements. For instance, the vibration amplitude of the storage ring quadrupoles is restricted to 0.11 μm (rms) over a frequency range of 4–50 Hz. Damping pads, consisting of thin viscoelastic films sandwiched between stainless steel plates, have been designed for passive vibration damping. Results presented in this paper show that the damping pads under the storage ring girder-magnet assemblies reduced the vibration amplification factor Q from over 100 to 8. The broad band rms motion of the magnets was reduced by a factor of 2.5 to 3. Preliminary results for a monochromator housing show a potential use of such damping pads for vibration control of beamline components. Radiation and creep effects on the damping pads' performance are considered.

Alignment and commissioning of the APS beamline front ends

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Fifteen out of forty initial beamline front ends have been installed in the storage-ring tunnel at the 7-GeV Advanced Photon Source (APS). For the front-end installation, a four-step alignment process was designed and consists of (1) prealigning the front-end components with support tables in the preassembly area, (2) installing the components with tables in the storage-ring tunnel and aligning relative to the APS global telescope survey network, (3) confirming the alignment using a tooling laser alignment system, and (4) performing adjustments with the synchrotron-radiation beam during commissioning. The laser alignment system and the prealignment database have been of great importance for the expedient maintenance of front-end components. These tools are very important to a large synchrotron radiation facility, such as the APS, since they make a quick alignment setup possible and minimize alignment time inside the tunnel. This paper will present the four-step alignment process, the laser alignment system, and discuss the alignment confirmation results.

Design of the commissioning filter/mask/window assembly for undulator beamline front ends at the Advanced Photon Source

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A compact filter/mask/window assembly has been designed for undulator beamline commissioning activity at the Advanced Photon Source beamlines. The assembly consists of one 300-μm graphite filter, one 127-μm CVD diamond filter and two 250-μm beryllium windows. A water-cooled Glidcop fixed mask with a 4.5 mm$\times$4.5 mm output optical aperture and a 0.96 mrad$\times$1.6 mrad beam missteering acceptance is a major part in the assembly. The CVD diamond filter, which is mounted on the downstream side of the fixed mask, is designed to also function as a transmitting x-ray beam position monitor. The sum signal from the latter can be used to monitor the physical condition of the graphite filter and prevent any possible chain reaction damage to the beryllium windows downstream. In this paper, the design concept as well as the detailed structural design of the commissioning window are presented. Further applications of the commissioning window components are also discussed.

White beam transport design for insertion device beamlines at the Advanced Photon Source
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To evaluate the feasibility of designing an economic beamline transport system for insertion device beamlines at the Advanced Photon Source, two sample cases have been designed and analyzed, one for an undulator source and the other for a wiggler source. The results show that it is possible to build a 70-meter-long beamline transport system for an undulator source with less than four lead/tungsten-alloy bremsstrahlung collimators. Six or fewer collimators are needed to construct a 70-meter-long white-beam transport system for a wiggler source. To prevent damage from any missteered powerful white beam, a water-cooled fixed mask is placed in front of each collimator. Ray tracing for both bremsstrahlung and synchrotron radiation have been conducted for the sample transports. Modular mask/collimator assembly designs and ray-tracing results are presented.

An intelligent filter control system using fuzzy logic for APS insertion device beamlines
Deming Shu, Jim Minich, Dean Haeffner, Christa Brite, Tom Nian, Roger Dejus, and Tuncer Kuzay *Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory, 9700 S. Cass Ave., Argonne, IL 60439* (Presented on 20 October 1995)

A modular filter has been designed for the white-beam undulator/wiggler beamlines at the Advanced Photon Source. For a typical hard x-ray application, the filter assembly consists of four filter banks, and each bank has five beam apertures. Therefore a maximum of 625 filter combinations is mechanically possible. To prevent any mistaken setup, which could either damage the filter itself or downstream optical components, a programmable logic controller (PLC) based protection system has been designed. Fuzzy logic was used in this system to limit the memory size and improve the system performance. Ten different storage-ring beam currents and ten insertion-device gap setups have been chosen to cover a large dynamic operation range. Aspects of the system fuzzy logic design as well as an example of the calculated results for the control database are presented in this paper.

Redesigned front end for the upgrade at CHESS Randall L. Headrick and Karl W. Smolenski *CHESS, Cornell University, Wilson Lab., Ithaca, NY 14853* (Presented on 20 October 1995)

We will report on beamline front-end upgrades for the 24-pole wiggler beamlines at CHESS. A new design for primary x-ray beamstops based on a tapered, water-cooled copper block has been implemented and installed in the CHESS F beamline. The design uses a horizontally tapered ''V'' shape to reduce the power density on the internal surfaces and internal water channels in the block to provide efficient water cooling. Upstream of the beam stops, we have installed a new photoelectron style beam position monitor with separate monitoring of the wiggler and dipole vertical beam positions and with micron-level sensitivity. The monitor's internal surfaces are designed to absorb the full x-ray power in case of beam missteering, and the uncooled photoelectron collecting plates are not visible to the x-ray beam. A graphite prefilter has been installed to protect the beryllium windows that separate the front end from the x-ray optics downstream. The redesigned front end is required by the upgrade of the Cornell storage ring, now in progress, which will allow stored electron and positron currents of 300 mA by 1996, and 500 mA by 1998. At 500 mA, the wiggler power output will be over 32 kW.

Special manufacturing/joining techniques used in the manufacture of the Advanced Photon Source (APS) front-end and beamline components
M. C. Townsend *Oxford Instruments Accelerator Technology Group, Osney Mead, Oxford OX2 0DX, UK* (Presented on 17 October 1995)

The front ends and beamlines of the Advanced Photon Source (APS) are designed to control, define, and/or confine the x-ray beam. Power densities of the order of 500 watts/mm^2 are generated by the intense undulator beams, thus conventional materials and cooling techniques for beam stops, slits and masks are inadequate. Extensive use of Glidcop®, tungsten and molybdenum has been made in the design of these components; this has resulted in the need to develop and use specialized manufacturing/joining techniques. Experience gained using these techniques for the fabrication of APS front-end and beamline components is presented.

Performance analysis of the commissioning filter and window assembly for insertion device beamlines at the Advanced Photon Source T. M. Kuzay, H. L. Thomas Nian, Z. Wang, and D. Shu *Experimental Facilities Dvision, Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois 60439* (Presented on 20 October 1995)

Although the Advanced Photon Source (APS) undulator beamlines are designed for windowless operation, a special window assembly will be used during the commissioning phase of the beamlines until sufficient operational experience is gained with the powerful undulator A photon beam. This assembly is called a ''commissioning window.'' The commissioning window assembly as designed consists of a 300-μm-thick filter (made of graphite), a fixed mask (made of Glidcop), a multipurpose transmitting filter/BPM disk (made of 127-μm-thick CVD diamond), and set of a double windows (made of 250-μm-thick beryllium). Due to the high total power and power density, the filter/window assembly must be carefully designed to guarantee longevity and satisfactory performance throughout its service. Hence extensive analytical work has been

conducted on various thermal and structural aspects of the commissioning window assembly. This paper summarizes the analytical results and presents the expected performance characteristics of the as-designed commissioning window.

Using metallic filters in APS undulator beamlines
Zhibi Wang and Tuncer M. Kuzay *Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439* (Presented on 20 October 1995)

Metallic filters are needed by APS users in their beamlines. Two general areas of use for the white-beam metallic filters are: (1) to attenuate the x-ray beam to reduce the thermal load during routine operations and (2) to attenuate the x-ray beam during alignment and for special testing of optics at low power. Metallic filters are important for users who will be working primarily in the high energy x-ray range because unwanted lower energy photons are absorbed through the metallic filters. Notwithstanding their high thermal conductivity, the metals, in general, absorb x-rays significantly near surface layers and hence can attain very large temperatures causing structural deformations and/or damage. Thermomechanical behavior and failure prediction need to be done carefully. In this paper, particulars of metallic filters are discussed and generalized analytical solutions are offered to help users of metallic filters determine their applicability for x-ray beamlines

On filter design and critical thickness of synchrotron x-ray filters
Zhibi Wang and Tuncer M. Kuzay *Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439* (Presented on 20 October 1995)

A ''critical thickness'' for a synchrotron radiation x-ray filter exists. Because x-ray absorption in media is an exponential function of depth and because radiation and conduction both play a role in the cooling of the filter assembly, the heat transfer mechanism changes from radiation dominant to conduction dominant as the thickness increases. For a thin filter, radiative heat transfer is the main mechanism. The maximum temperature in the filter increases as the thickness increases due to the fact that the total heat load increases while the total area for radiative heat transfer remains the same. For a thick filter, conductive heat transfer is the main cooling mechanism. When the filter thickness increases, the heat absorption per unit thickness decreases and so does the maximum temperature. At a certain thickness, the temperature in the filter is the maximum. This is the critical thickness. For third-generation synchrotron radiation facilities, the maximum temperature and thermal stresses in a filter are the main factors considered in a filter assembly design. It is very important to avoid designing a filter inside the critical thickness range.

Design and analysis of a photon/safety shutter for CARS sector 14 ID beamline at the Advanced Photon Source
W. Schildkamp, Y. Jaski, and G. Navrotski *Consortium for Advanced Radiation Sources, University of Chicago, 5640 S. Ellis Ave., Chicago, IL 60637* (Presented on 20 October 1995)

A photon/safety shutter capable of stopping bremsstrahlung, white, pink, and monochromatic radiation from the APS wiggler and undulator sources is described. The shutter consists of two individually actuated but redundant block assemblies. Each block consists of a water-cooled, OFHC block thermal absorber followed by a tungsten block to stop both synchrotron and bremsstrahlung rays. The design presented here is inexpensive and spatially compact. Fatigue analysis and ANSYS thermal and stress analysis are presented.

Internally shielded beam transport and support system
W. Schildkamp and H. Brewer *Consortium for Advanced Radiation Sources, University of Chicago, 5640 S. Ellis Ave., Chicago, IL 60637* (Presented on 20 October 1995)

Due to environmental concerns, the Advanced Photon Source has a policy that disallows any exposed lead within the facility. This creates a real problem for the beam transport system, not so much for the pipe but for the flexible coupling (bellows) sections. A complete internally shielded x-ray transport system, consisting of long transport lines joined by flexible coupling sections, has been designed for CARS sector 14 to operate either at high vacuum or as a helium flight tube. It can effectively shield against air scattering of wiggler or undulator white beam with proper placement of apertures, collimators, and masks for direct beam control. The system makes use of male- and female-style fittings that create a labyrinth allowing for continuous shielding through the flexible coupling sections. These parts are precision machined from a ternary hypereutectic lead alloy (cast under 15 inches of head pressure to assure a pinhole-free casting) then pressed into either end (rotatable vacuum flanges) of the bellows assembly. The transport pipe itself consists of a four part construction using a stepped transition ring (Z-ring) to connect an inner tube to the vacuum flange and also to a protective and supportive outer tube. The inner tube is wrapped with 1/16″ pure lead sheet to a predetermined thickness following the shape of the stepped transition ring for continuous shielding. This design has been prototyped and radiation tested.

Secondary bremsstrahlung dose rates from glancing incidence target P.K. Job and D.R. Haeffner *Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439* (Presented on 20 October 1995)

Several collaborative access teams at the Advanced Photon Source (APS) are planning to use a vertically or horizontally reflecting mirror as the first optical element in the insertion device beamlines. The scattering of the bremsstrahlung from the glancing incidence mirrors is significantly different than that from normal incidence targets. The Electron Gamma Shower program (EGS4) was used to calculate the angular distribution of the scattered secondary bremsstrahlung from copper and silicon glancing incidence mirrors. These calculations were done for an incident angle of 0.15°. Pair production, positron annihilation at rest and in flight, Moliere multiple scattering, Moller and Bhabha scattering, delta ray production, Compton scattering, the photoelectric effect, and the continuous energy loss by Bethe-Bloch formalism were the processes simulated in this calculation. The dose at one meter away from the mirror, due to the scattered secondary bremsstrahlung, was calculated from the energy deposited in the standard ICRU tissue placed at that location. Since the EGS4 result is expressed as the dose per photon, the dose rate was obtained by multiplying the dose per photon by the total number of photons produced in unit time in the insertion device vacuum chamber. The dose rate results and its implication for the design of the first optical enclosures are presented in this paper.

Design analysis of a composite L5-20 slit for x-ray beamlines at the Advanced Photon Source

H.L. Thomas Nian, Tuncer M. Kuzay, D. Shu, and C. Benson *Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439* (Presented on 20 October 1995)

White-beam slits are precision high heat load devices used on beamlines of the Advanced Photon Source (APS) to trim and shape the incoming x-ray beam before the beam is transmitted to other optical components. At the APS, the insertion devices that generate the x-ray beams are very powerful. For example, the heat flux associated with an x-ray beam generated by undulator A will be on the order of 220 W/mm^2 at the L5-20 slit location (about 27.5 m away from the insertion device) at normal incidence. The total power is about 6 kW. Optical slits with micron-level precision are very difficult to design under such heat flux and total power considerations. A novel two-metal composite slit has been designed to meet the diverse thermal, structural, and precision requirements. A commercial code, ANSYS, has been used as the finite element source for the analysis of the optimized design for the set.

Closed-form solutions for a disk, a filter, and a window for an x-ray beamline at the Advanced Photon Source

H. L. Thomas Nian and Tuncer M. Kuzay *Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439* (Presented on 20 October 1995)

Several temperature closed-form solutions are developed and presented in this paper. The heating on a one-dimensional thin disk and a two-dimensional thin plate are analyzed. Parametric studies are also included to determine the optimized temperature for the designs.

Thermal buckling parametric analysis for a diamond disk for a x-ray beamline at the Advanced Photon Source

H. L. Thomas Nian, Tuncer M. Kuzay, and I. C. Sheng *Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439* (Presented on 20 October 1995)

A thermal buckling analysis for a diamond disk in the commissioning window assembly designed for x-ray beamlines at the Advanced Photon Source is presented. The analytical solution together with associated numerical analysis help to predict the critical temperature of the diamond disk before a thermal buckle occurs.

Mechanical design of a missteered beam safety monitor at the Advanced Photon Source

J. Chang, D. Shu, G. Decker, T. Nian, T.M. Kuzay, A. Lumpkin, and X. Wang *Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439* (Presented on 20 October 1995)

A missteered beam safety monitor (MBSM) has been designed to protect the accelerator ring of the Advanced Photon Source against incursions of the missteered synchrotron radiation. When the orbit of the particle beam in the accelerator shifts out of its safety limits, the photon beam from the bending magnet will pass through the square apertures on the cooled mask of the MBSM and will heat up a very thin tungsten wire (0.025 mm in diameter) behind the mask. Acting as a resistance thermometer, the electrical resistance of the tungsten wire increases proportionally with temperature rise. As soon as the electrical resistance of the tungsten wire reaches a preset point, a signal is triggered immediately to dump the particle beam in the accelerator. The tungsten wire is inclined to the photon beam at 4.5 degrees in the vertical direction to prevent it from being overheated by the high power photon beam. Detailed mechanical design and thermal analysis are presented.

Flux, irradiance, and transmission calculations for the ALS wiggler beamline 5.0

S. Marks and C. Cork *Earnest Orlando Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, California* (Presented on 20 October 1995)

A protein crystallography facility is being constructed for the Advanced Light Source (ALS) wiggler beamline 5.0. The radiation source is a 38 pole, 2.0 T wiggler. Calculations have been performed to determine the source phase space characteristics and the power loading on and transmission of various beamline elements. A set of computer codes have been developed for this purpose. The wiggler horizontal and vertical phase space flux density is calculated by *phasex* and *phasey*, respectively. *WrFlux* calculates the spectral flux density along the principal ray of the optical system. *WrPwr* calculates the power impinging on a target. If a filter function is specified, the transmitted, or reflected, power is calculated. The theory and operation of the codes will be presented as well as several results of calculations.

Monte Carlo simulations of the vacuum performance of differential pumps at the Advanced Photon Source

C. Liu, D. Shu, T. M. Kuzay, and R. Kersevan* *Experimental Facilities Division, Advanced Photon Source, Argonne National Lab, Argonne, IL 60439 * Wilson Lab of Nuclear Studies, Cornell University, Ithaca, NY 14853* (Presented on 20 October 1995)

Monte Carlo computer simulations have been successfully applied in the design of vacuum systems. These simulations allow the user to check the vacuum performance without the need of making a prototype of the vacuum system. In this paper we demonstrate the effectiveness and aptitude of these simulations in the design of differential pumps for synchrotron radiation beamlines. Eventually a good number of the beamline front ends at the Advanced Photon Source (APS) will use differential pumps to protect the synchrotron storage ring vacuum. A Monte Carlo computer program is used to calculate the molecular flow transmission and pressure distribution across the differential pump. A differential pump system, which consists of two 170 l/s ion pumps with three conductance-limiting apertures, was previously tested on an APS insertion-device beamline front end. Pressure distribution measurements using controlled leaks demonstrated a pressure difference of over two decades across the differential pump. A new differential pump utilizes a fixed mask between two 170 l/s ion pumps. The fixed mask, which has a conical channel with a small cross section of 4.5×4.5 mm^2 in the far end, is used in the beamline to confine the photon beam. Monte Carlo simulations indicate that this configuration with the fixed mask significantly improves the pressure reduction capability of the differential pump, to $\sim3\times10^{-5}$, within the operational range from $\sim10^{-4}$ to 10^{-10} Torr. The lower end of pressure is limited by outgassing from front-end components and the higher end by the pumping ability of the ion pump.

Importance of components cleaning in the ultrahigh vacuum performance of beamline front ends

C. Liu, J. T. Collins, R. W. Nielsen, T. L. Kruy, M. Ramanathan, and T. M. Kuzay *Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439* (Presented on 20 October 1995)

The Advanced Photon Source (APS) has 40 beamline front ends in its initial phase of operations; eventually a total of 69 beamline front ends will be connected to the storage ring. The ultrahigh vacuum performance of these front ends will have a significant impact on the storage ring vacuum and on the lifetime of the positron beam. In this paper we emphasize the importance of proper component cleaning to the ultrahigh vacuum performance of beamline front ends. Critical issues in the cleaning process include using environmentally friendly cleaning agents and applications of ultrasonic agitation, thorough deionized water rinsing, and vacuum furnace baking. A simple and cost-effective cleaning facility consisting of ultrasonic cleaning tanks, a drying tank, and a vacuum furnace has been set up. The effectiveness of component cleaning is evaluated by the base pressure achievable in comparison to what is expected according to vacuum calculations using available outgassing rates for the components. Each major component is vacuum tested before final assembly. Vacuum comparisons in some vendor-provided components before and after additional cleaning will be discussed.

Cleaning and outgassing studies of machinable tungsten for beamline safety shutters

C. Liu, D. Ryding, R. W. Nielsen, T. L. Kruy, and T. M. Kuzay *Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439* (Presented on October 20, 1995)

Machinable tungsten blocks are used as safety shutters in the front ends and the beamlines at the Advanced Photon Source (APS). The machinable tungsten used is characterized as a UHV-compatible metal by the vendor and was developed through a joint research effort with the APS. However, because of the inherent porosity in the sintered tungsten metal, it may present a vacuum problem and has to be subjected to strict vacuum testing before it is put on the beamlines. We have chosen specially heat-treated machinable tungsten with a density of 18 g/cm^3 for safety shutters. In-house-developed, environmentally friendly vacuum cleaning procedures were used. In this paper, we present results of thermal outgassing tests for machinable tungsten safety shutter sets. Each set consists of five blocks and has a total area of 4500 cm^2. A cleaning procedure using alkaline detergent ultrasonic washes, deionized water rinses, and a 500 °C vacuum furnace baking was used before outgassing measurements. Outgassing rates 10 hours after initial pump down at room temperature reached $\sim 1.60\times10^{-10}$ $Torr\cdot l\cdot s^{-1}\cdot cm^{-2}$ for machinable tungsten and $\sim 1.56\times10^{-10}$ $Torr\cdot l\cdot s^{-1}\cdot cm^{-2}$ for the stainless steel vacuum chamber. The outgassing rate of machinable tungsten 24 hours after an *in situ* 48 h bake at 160 °C is also comparable to that of the stainless steel vacuum chamber. The importance of a 500 °C vacuum furnace baking has been confirmed by outgassing studies for machinable tungsten sets that were not subject to vacuum furnace baking.

CHESS upgrade 1995: Improved radiation shielding

K.D. Finkelstein *CHESS, Cornell University, Ithaca, NY 14853* (Presented on 20 October 1995)

The Cornell Electron Storage Ring (CESR) stores electrons and positrons at 5.3 GeV for the production and study of B mesons, and, in addition, it supplies synchrotron radiation for CHESS. The machine has been upgraded for 300 mA operation. It is planned that each beam will be injected in about 5 minutes and that particle beam lifetimes will be several hours. In a cooperative effort, staff members at CHESS and LNS have studied sources in CESR that produce radiation in the user areas. The group has been responsible for the development and realization of new tunnel shielding walls that provide a level of radiation protection from 20 to >100 times what was previously available. Our experience has indicated that a major contribution to the environmental radiation is not from photons, but results from neutrons that are generated by particle beam loss in the ring. Neutrons are stopped by inelastic scattering and absorption in thick materials such as heavy concrete. The design for the upgraded walls, the development of a mix for our heavy concrete, and all the concrete casting was done by CHESS and LNS personnel. The concrete incorporates a new material for this application, one that has yielded a significant cost saving in the production of over 200 tons of new wall sections. The material is an artificially enriched iron oxide pellet manufactured in vast quantities from hematite ore for the steel-making industry. Its material and chemical properties (iron and impurity content, strength, size and uniformity) make it an excellent substitute for high grade Brazilian ore, which is commonly used as heavy aggregate in radiation shielding. Its cost is about a third that of the natural ore. The concrete has excellent workability, a 28 day compressive strength exceeding 6000 psi and a density of 220 lbs/cu.ft (3.5 gr/cc). The density is limited by an interesting property of the pellets that is motivated by efficiency in the steel-making application. The pellets are made to be porous, with about 28% of the volume consisting of connected pores of size typically from 1–10 microns. The porosity may have some useful implications for neutron radiation shielding including the possibility of holding a lot more water than a conventional mix, and the opportunity to impregnate the pellets with a good neutron absorber such as boron. This paper will discuss these developments and report the latest results on the effectiveness of the upgraded shielding at Cornell.

X-ray microfabrication activities at the Center for Advanced Microstructures and Devices (CAMD)

C. Khan Malek, Y. Vladimirsky, O. Vladimirsky, J. Scott, B. Craft, and V. Saile *Center for Advanced Microstructures and Devices, Louisiana State University, 3990 West Lakeshore Drive, Baton Rouge, LA 70803* (Presented on 17 October 1995)

The x-ray lithography and micromachining facility at CAMD is described. It consists of four dedicated beamlines and exposure stations using the synchrotron radiation delivered by the CAMD storage ring and 230 m^2 of fully equipped clean room. The scientific and engineering activities exemplified by results of current studies are reported.

Innovations in the design of mechanical components for a beamline—The SRI'95 Workshop 2 Summary

T.M. Kuzay and T. Warwick* *Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439 *Advanced Light Source, Lawrence Berkeley Laboratory,*

Berkeley, CA 94720 (Presented on 17 October 1995)

The Synchrotron Radiation Instrumentation 1995 Conference (SRI'95) was hosted by the Advanced Photon Source (APS) at Argonne National Laboratory (ANL). Of the many workshops within the conference, the SRI'95 Workshop 2 was ''Innovations in the Design of Mechanical Components of a Beamline.'' The workshop was well attended with over 140 registrants. The following topics were discussed. Industry's perspective on the status and future was provided by Huber Diffraktionstechnik GMBH on goniometers/diffractometers, Oxford Instruments on advanced manufacturing technique of high heat load components, such as the APS photon shutter, and Kohzu Seiki Co. Ltd. on the specialties of monochromators provided to the third-generation synchrotrons. This was followed by a description of the engineering of a dual function monochromator design for water-cooled diamond or cryogenically cooled silicon monochromators by CMC CAT/APS. Another category was the nagging problem of sensitivity of the photon beam position monitors (XBPM) to bending magnet radiation (''BM contamination'') and the undulator magnet gap changes. Problem descriptions and suggested solutions were provided by both the Advanced Light Source (ALS) and the APS. Other innovative ideas were the cooling schemes (enhanced cooling of beamline components using metallic porous meshes including cryo-cooled applications); Glidcop photon shutter design using microchannels at the ALS; and window/filter design, manufacture and operational experiences at CHESS and PETRA/HASYLAB. Additional discussions were held on designing for micromotions and precision in the optical support systems and smart user filter schemes. This is a summary of the presentations at the Workshop.

Radiation shielding and personal protection at synchrotron radiation sources T. Rauchas *Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439* (Presented on 17 October 1995)

The workshop provided a forum for synchrotron facility designers and operators to discuss the following topics: aspects of shielding of high-energy synchrotron radiation facilities, radiation backgrounds, personnel protection systems, and aspects of implementation of the DOE Accelerator Safety Order. The workshop format consisted of presented papers with adequate time provided for discussion groups and round-table discussions.

Workshop on performance optimization of synchrotron radiation storage rings

G. Decker *Accelerator Systems Division, Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439* J. Safranek *National Synchrotron Light Source, Brookhaven National Laboratory, Upton, NY 11973* (Presented on 17 October 1995)

The purpose of this workshop was to provide a forum, with user participation, for accelerator physicists working in the synchrotron light source field to discuss current and planned state-of-the-art techniques to optimize storage ring performance. The scope of the workshop focused on two areas: lattice characterization and measurement, and fundamental limitations on low frequency beam stability.

Beam stabilization at SPEAR

J. Corbett *SSRL Accelerator Department, Stanford Synchrotron Radiation Laboratory/SLAC, Stanford University, CA 94309* (Presented on 17 October 1995)

The SPEAR storage ring began routine synchrotron radiation operation with a dedicated injector in 1990. Since then, a program to improve beam stability has steadily progressed. This paper, based on a seminar given at a workshop on storage ring optimization (1995 SRI conference) reviews the beam stability program for SPEAR.

Beamline instrumentation for short-wavelength FELs

Erik Johnson *National Synchrotron Light Source, Brookhaven National Laboratory, Bldg. 725D, Upton, NY 11973* (Presented on 18 October 1995)

This workshop examine the uniqued requirements of beamlines at short-wavelength FELs, including detector requirements. Additional topics were the heat loads from a short-wavelength FEL, optics for a short-wavelength FEL beamline, and new technologies using short-wavelength FELs.

Summary of the workshop on "X-ray Optics and Ray Tracing: Status and Needs"

F. Cerrina,[1] S.L. Hulbert,[2] and M. Sanchez del Rio[3] [1] *University of Wisconsin-Madison, Center for X-ray Lithography, 1415 Engineering Drive, Madison, WI 53706-1691* [2] *Brookhaven National Labs, 75 Brookhaven Avenue, Upton, NY 11973* [3] *European Synchrotron Radiation Facility, BP220 Grenoble Cedex, France 38043* (Presented on 18 October 1995)

A workshop on x-ray optics and ray tracing was held on October 18, 1995, at the Synchrotron Radiation Instrumentation conference held at Argonne. The object of the workshop was to exchange experience in ray-tracing calculations between the largest synchrotron radiation facilities. The introduction was carried out by Franco Cerrina, who made a review presentation of SHADOW, the only ray-tracing code that can be used for almost all the synchrotron radiation applications and surely is the most wide-spread and complete one. Then a total of seven speakers presented in short talks (20 minutes) their experience in the use of SHADOW at their respective facilities, their developments, suggestions, wishes, and complaints about some points of the package. Some of the presentations are available as contributed papers to the SRI'95 proceedings. In general, the speakers (representing all the U.S. Department of Energy synchrotron radiation sources) felt that the program was an essential part of the facilities experimental development.

Use of the program SHADOW in designing a capillary focusing beamline

F. C. Brown, K. H. Kim, S. M. Heald, B. M. Barg, and E. A. Stern *Department of Physics, Box 351560, University of Washington, Seattle, WA 98195-1560* (Presented on 18 October 1995)

In this report we consider the use of the program SHADOW for ray tracing different configurations of the PNC-CAT mircrofocus beamline. The emphasis is on the final design, which will include crystal and grazing incidence optics focusing onto the entrance of a long tapered glass capillary whose outlet diameter is of the order of one micron or less. The ray-tracing program has been especially valuable in comparing different configurations, determining the required

stability of components, and optimizing the capillary profile. It has also been useful in evaluating the results of actual measurements on the throughput of long tapered capillaries fabricated of silica glass. Suggestions for improvements to SHADOW are given. We also present results of a compact pc-based capillary ray-tracing program for comparison. It allows us to use different profiles with minimal programming effort.

Experience with ray-tracing simulations at the European Synchrotron Radiation Facility

Manuel Sánchez del Río *European Synchrotron Radiation Facility, BP 220, F-38043 Grenoble Cedex 9, France* (Presented on 18 October 1995)

The ESRF is the first operational third-generation synchrotron radiation hard-x-ray source. Since the beginning of its construction (1988), the ray-tracing technique proved to be an essential computer tool for beamline optics design. The optical systems of most beamlines have been simulated by ray tracing in order to optimize the optics, fully understand their properties, and check if operation performances were as expected. In this paper, a short compilation of the experience with ray tracing and optics simulation codes at the ESRF, as well as some other in-house developments, is presented.

Ray tracing: Experience at SRC

Mary Severson *Synchrotron Radiation Center, University of Wisconsin-Madison, 3731 Schneider Drive, Stoughton, WI 53589* (Presented on 18 October 1995)

SHADOW [B. Lai and F. Cerrina, Nucl. Instrum. Methods A **246**, 337 (1986)] is the primary ray-tracing program used at SRC. Ray tracing provides a tremendous amount of information regarding beamline layout, mirror sizes, resolution, alignment tolerances, and beam size at various locations. It also provides a way to check the beamline design for errors. Two recent designs have been ray traced extensively: an undulator-based, 4-meter, normal-incidence monochromator (NIM) [R. Reininger, M.C. Severson, R.W.C. Hansen, W.R. Winter, M.A. Green, and W.S. Trzeciak, Rev. Sci. Instrum. **66**, 2194 (1995)] and an undulator-based, plane-grating monochromator (PGM) [R. Reininger, S.L. Crossley, M.A. Lagergren, M.C. Severson, and R.W.C. Hansen, Nucl. Instrum. Methods A **347**, 304 (1994)].

Report on the SRI '95 workshop on the timing structure of the Advanced Photon Source

E. E. Alp *Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois 60439* (Presented on 20 October 1995)

The workshop on the timing structure of the Advanced Photon Source (APS) brought synchrotron radiation experimentalists and accelerator physicists together to discuss the potential experiments and capabilities of this new machine. The discussions represented only a small subset of possibilities, those that use the built-in time structure of the synchrotron radiation. Similarly, the capabilities of the APS machine, beyond the design parameters, reflect the limited experience the accelerator physicists have had with this machine, which is currently going through a commissioning period. Therefore, projections based on this report may be premature. However, we hope that some of the experimentalists' needs are better understood by the accelerator physicists and that the limitations of the machine are better understood by the synchrotron radiation experimentalists.

Photon beam diagnostics and characterization tools

W. Yun *Experimental Facilities Division, Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois 60439* (Presented on 19 October 1995)

Photon beam diagnostics and characterization are very important to the production and effective use of synchrotron x-ray beams. Proper diagnostic tools, techniques, and procedures are useful not only for initial commissioning of a beamline but also for its maintenance. In some cases, it is essential to have some beam diagnostic and characterization capabilities as an integral part of the overall beamline design. On-line characterization tools can also assist the user in specimen alignment and in setting up experiments. Important parameters of a photon beam include absolute flux, energy spectrum, coherence properties, spatial and angular distribution, polarization state, timing structure, and position and angular stability. A separate workshop focuses on the timing structure, and the conference has an invited talk on polarization characterization. Consequently, this workshop concentrated on the following two topics: • Measurement of the insertion-device and bending-magnet source characteristics: particle beam emittance, spectrum, and angular distribution. • Characterization of the radiation at the end of a beamline: absolute flux, resolution, spot size, and higher-order content. Simple, inexpensive techniques for photon beam characterization were emphasized. The workshop format included presentations by invited speakers with extensive experience at various synchrotron facilities, invited presentations, and general discussion. Time was also available for general discussion.

Alternative Methods for Sub-eV Resolution Inelastic X-ray Scattering

Albert T. Macrander *Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439* Philip M. Platzman *AT&T Bell Laboratories, Murray Hill, NJ 07974* (Presented 20 October 1994)

A synopsis of SRI workshop 9 held on October 20, 1995, is given. Details concerning the oral presentations of speakers not contributing to these proceedings are included. The workshop consisted of the following invited presentations: 1. M. Schwoerer-Boehning (APS), ''Experimental Needs for Milli-eV Resolution Inelastic X-ray Scattering, '' 2. E. E. Alp (APS), ''Inelastic Nuclear Resonant X-ray Scattering,'' 3. A. Baron (ESRF), '' Inelastic X-ray Scattering via Nuclear Resonant Analyzer,'' 4. D. E. Moncton (APS), '' An Exact Backscattering Beamline,'' 5. A. Caticha (SUNY-Albany), ''X-ray Fabry-Perot Cavities,'' 6. E. D. Isaacs (AT&T Bell Labs), ''Flux and Resolution Requirements for Studies of Electronic Excitations in Solids,'' 7. C. K. Stahle (NASA), ''Hard X-ray Detectors with Very High Energy Resolution,'' 8. A. K. Freund (ESRF), ''Mosaic Crystal Analyzers.'' These proceedings contain separate papers by Caticha, Isaacs, and Stahle for the above listed presentations, and we will not discuss them further here. The other presentations are summarized below.

A Fabry-Perot interferometer for sub-meV x-ray energy resolution

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The optical theory of Fabry-Perot interferometers (FPIs) for x rays using dynamically diffracting thin perfect crystals as reflectors is

developed. Application to a device using high diffraction orders in silicon crystals of thickness of the order of 100 μm or more shows that energy resolutions of the order of a tenth of a meV are achievable. The effect that various features, such as gap and mirror thickness, lattice mismatches, etc., have on the FPI resonances is studied.

Flux and resolution requirements for studies of electronic excitations in solids

E.D. Isaacs and P.M. Platzman *AT&T Bell Laboratories, 600 Mountain Avenue, Murray Hill, NJ 07974* (Presented on 20 October 1995)

Advances in synchrotron sources promise to open a new frontier in the use of inelastic x-ray scattering to probe electronic excitations on the eV and sub-eV energy scales. In this paper we present the flux and resolution requirements for inelastic scattering in condensed matter systems. A review of several recent results will be given along with several proposed experiments.

Cryogenic high resolution x-ray detectors—status, theoretical limits, and suitability for synchrotron radiation inelastic scattering experiments

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There are several kinds of low temperature solid-state x-ray detectors presently under development, motivated primarily by the need for high resolution, efficient spectrometers for x-ray astronomy. These include calorimeters, nonequilibrium phonon sensors, and charge collection devices using superconducting tunnel junctions. Energy resolution at 6 keV of order 1 eV has been predicted for all of these devices, though the best measured to date, 7 eV FWHM, has been obtained with calorimeters with semiconductor thermistors. This paper will address the difference between prediction and performance for the different classes of devices. The theoretical limits will be discussed in light of the need in inelastic scattering experiments for using x rays with energy greater than 20 keV. The potential for sub-eV resolution will also be addressed.