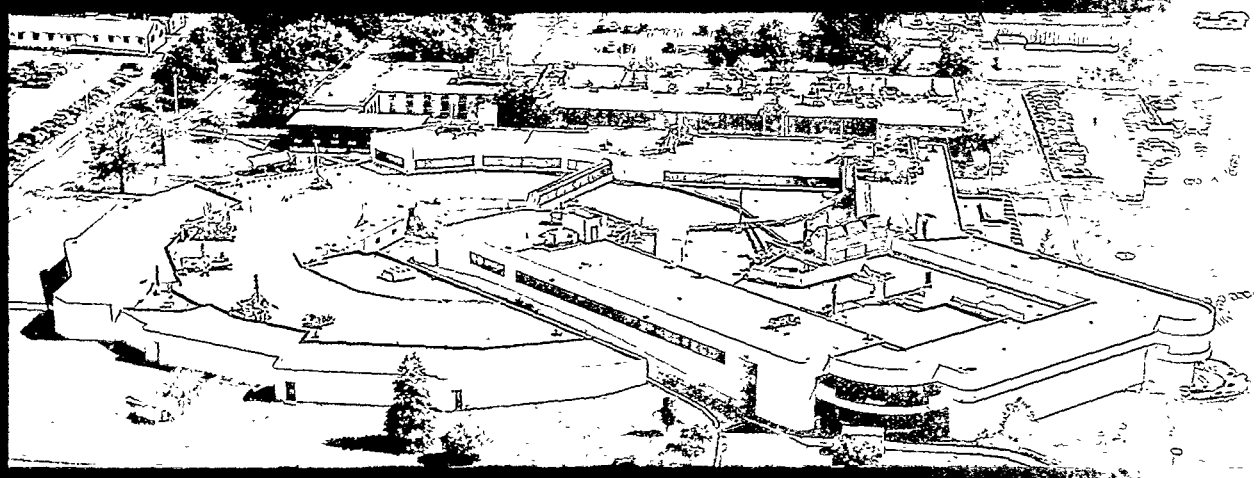
Lighting the Way to the Future:

An Anthology of Improvements, Developments, and Research by NSLS Staff and Collaborators



National Synchrotron Light Source Brookhaven National Laboratory

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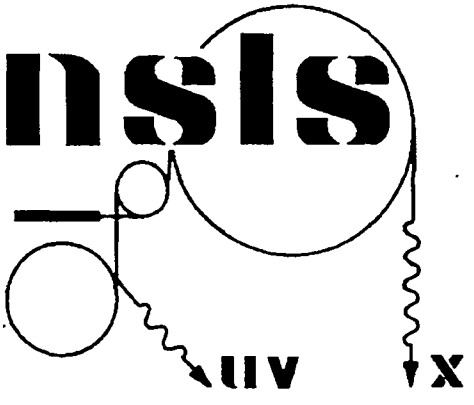

National Synchrotron Light Source

Brookhaven National Laboratory
Associated Universities, Inc.
Upton, NY 11973

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PREFACE

Following the commissioning phase of a scientific facility, it is essential to invent, adapt and improve new technologies so that the specification and performance of the facility is upgraded over it's lifetime. It is equally important that staff keep their expertise and research interests at the cutting edge and contribute, based on their unique experience, to the present and next generation of experiments at existing facilities and to the specification and R & D on which the next generation of facilities will be based.

A synchrotron radiation facility such as the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory supports a very wide range of science which is dependent on the breadth of the electromagnetic spectrum which is generated. Scientists from many disciplines use radiation from the far infra-red (λ = 12 mm, Energy = 0.1 meV) through to extreme gamma rays (λ = 4 fm, Energy = 300 MeV). All aspects of the facility need continual improvement, development and research including the source itself, the optics of beamlines, experimental concepts and the performance of detectors. This collection of papers shows the scope of past work by NSLS staff and their collaborators, serves as a reminder of their achievements and as an indicator of the range, quality and quantity of work which is required to maintain a scientific user facility at the cutting edge.

Michael Hart
Chairman, NSLS

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SEMINAL PAPERS ON STORAGE RING CONCEPTS

Coherent Synchrotron Radiation in the SXLS Phase I Electron Storage Ring

J. B. Murphy, S. Krinsky, and R.L.Gluckstern, "Longitudinal Wakefield for Synchrotron Radiation," Proc. 1995 Part. Accel. Conf., Dallas, TX (1995).

*J. B. Murphy and S. Krinsky, "Millimeter Wave Coherent Synchrotron Radiation in the SXLS Phase I Electron Storage Ring," Nucl. Instrum. Meth. A **346**, 571 (1994).*

It is suggested that employing a superconducting RF cavity in the low energy SXLS Phase I storage ring would facilitate the generation of coherent synchrotron radiation in the far infrared. This might provide a path to extend the infrared program now rapidly growing on the VUV Ring. Also, operation of such a storage ring with electron bunch length (0.3mm) an order of magnitude shorter than presently achieved, will explore a new regime of accelerator physics, where the beam impedance due to synchrotron radiation is the dominant ring impedance.

SXLS Phase I Storage Ring

J. B. Murphy, R. Biscardi, J. Bittner, L.N. Blumberg, E. Bozoki, E. Desmond, H. Halama, R. Heese, H. Hsieh, J. Keane, S. Kramer, R. Nawrocky, T. Romano, J. Rothman, J. Schuchman, M. Thomas, J.M. Wang, "Commissioning of the Phase I Superconducting X-ray Lithography Source (SXLS) at BNL," Proc. 1991 IEEE Part. Accel. Conf., San Francisco, CA (1991) p. 1107.

R. Heese and T. Romano, "The Ultra-Fast Injection Kicker for SXLS," Proc. 1991 IEEE PAC, San Francisco, CA (1991), p. 993.

As part of the superconducting x-ray lithography source project funded by DARPA, a 200 MEV electron storage ring was built and commissioned to carry out studies of injection into compact storage rings. Currents as high as 1.3 Amp were stored. The novel injection scheme utilized a single fast kicker magnet.

Global Orbit Feedback: 1989 R&D 100 Award.

*L.H. Yu, E. Bozoki, J. Galayda, S. Krinsky, G. Vignola, "Real Time Harmonic Closed Orbit Correction," Nucl. Instrum. Meth. A **284**, 268 (1989).*

The first real time feedback systems to stabilize the entire orbit in a storage ring were developed at the NSLS. These systems have improved the orbit stability at the NSLS by an order of magnitude. We are now developing new digital global orbit feedback systems as an improvement over the existing analog systems. A digital design will allow more flexibility in the orbit correction algorithm and will provide for the use of an increased number of position monitors and correction dipoles.

Vignola Lattice

G. Vignola, "The Use of Gradient Magnets in Low Emittance Electron Storage Rings", Proc. Synch. Rad. Instrum. Conf., Stanford, CA (1985).

Gaetano Vignola developed a triple bend achromatic lattice utilizing gradients in the bending magnets. This design was adopted at Lawrence Berkeley National Laboratory for the Advanced Light Source storage ring.

Chasman-Green Lattice

R. Chasman, G. K. Green and E. M. Rowe, "Preliminary Design of a Dedicated Synchrotron Radiation Facility," IEEE Trans. Nucl. Sci. NS-22, 1765 (1975).

Proposal for NSLS (1977) BNL 50595, Vol. I and II.

This lattice was the first designed to optimize brightness of the synchrotron radiation sources and to provide many dispersion free straight sections for insertion devices. The design of the third generation hard x-ray sources (ESRF, APS, and SPring-8) are all based on the design of Chasman and Green.

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SEMINAL PAPERS ON SCIENCE WITH SYNCHROTRON RADIATION

X-ray Holography

S. Lindaas, M. Howells, C. Jacobsen, A. Kalinovsky, "X-ray In-line Holography Sub-50 nm Resolution Imaging Using Photoresists and Atomic Force Microscope Examination," Jour. of the Optical Soc. of America, 1996, in press.

S. Lindaas, M. Howells, C. Jacobsen, and A. Kalinovsky, "X-ray Holographic Microscopy via Photoresist Recording and Atomic-force Microscope Readout," J. Opt. Soc. Am. A 13, 1788 (1996).

C. Jacobson, M. Howells, J. Kirz, S. Rothman, "X-ray Holographic Microscopy Using Photoresists," Jour. Of the Optical Soc. Of America A 7, 1847-1861 (1990).

M. Howells and J. Kirz developed the first successful soft x-ray holographic apparatus at NSLS, initially on beamline U15 and subsequently using the X1 undulator beamline.

High Energy Resolution Resonant Raman Scattering

M.H. Krisch, C.-C. Kao, F. Sette, W.A. Caliebe, K. Hämäläinen, J.B. Hastings, "Evidence for Quadrupolar Contribution to the Absorption Cross Section at the L_{III} Edge of Gadolinium in Gadolinium Gallium Garnet," Phys. Rev. Lett. B 74, 4931 (1995).

X-ray resonant Raman scattering with total energy resolution of 1 eV is achieved. Since x-ray absorption near edge structure is the intermediate state in the resonant Raman process, analyzing the energies of the scattered photons with high resolution can be used to resolve overlapping features in the absorption spectra if the final states of these features can be separated energetically.

Speckle and Intensity Fluctuation Spectroscopy Using Coherent X-rays

S.B. Dierker, R. Pindak, R.M. Fleming, I.K. Robinson, and L.E. Berman, "X-ray Photon Correlation Spectroscopy Study of Brownian Motion of Gold Colloids in Glycerol," Phys. Rev. Letts. 75, 449 (1995).

M. Sutton, S.G.J. Mochrie, T. Greytak, S.E. Nagler, L.E. Berman, G.A. Held, and G.B. Stephenson, "Observation of Speckle by Diffraction with Coherent X-rays," Nature 352, 608 (1991).

Analysis of the scattering of coherent x-ray beams from disordered materials can provide a wealth of information on their static and dynamic structures, which cannot be had via other methods. In a pioneering experiment on beamline X25, the diffuse scatter, of a suitably-prepared coherent x-ray beam, from a disordered copper-gold alloy crystal was observed, and studied over time as the crystal was driven thermally into an ordered state, revealing the evolution of its ordered crystalline domains.

In a later experiment on X25, using a coherent x-ray beam of far higher intensity, the diffusion coefficient associated with the Brownian motion of gold colloid particles dispersed in a glycerol medium was measured through analysis of the temporal correlations among the scattered x-ray photons. The use of x-rays in these experiments, as compared with conventional visible light, has opened the possibility to study very short length scale dynamics, down to atomic length scales, in bulk materials (whether or not in equilibrium) that are opaque to other probes.

Soft X-ray Microscopy and Spectromicroscopy: 1991 R&D 100 Award

J. Kirz, C. Jacobsen, M. Howells, "Soft X-ray Microscopes and their Biological Applications," Quarterly Reviews of Biophysics ***28,*** *33 (1995).*

The scanning x-ray microscope was developed by Kirz (SUNY@SB) and Rahrback (NSLS). It provided improved performance and ease of alignment over the imaging x-ray microscopes popular in Europe. The adaptation of the scanning x-ray microscope to provide a microspectroscopic capability was done by Johnson (NSLS) and Ade (NCSU) in collaboration with Kirz. This unique capability enables a wide variety of important materials questions to be attacked, since even the same chemical species show different spectral features in the near-edge region. Thus, for example the different polymers in a polymer mixture can be mapped out using variations in the carbon K-edge structure.

H. Ade, J. Kirz, S. Hulbert, E. Johnson, E. Anderson and D. Kern, "Scanning Photoelectron Microscope with a Zone Plate Generated Microprobe," Nucl. Inst. & Meth. A ***291,*** *126 (1990).*

X-ray photoelectron spectroscopy (XPS) is a widely used, technologically important analytical technique for the study of surface chemistry and electronic structure. Standard XPS instruments are devoid of spatial resolution, and commercial (lab based) microscopes have resolution typically no better that 25-100 μm. This instrument takes advantage of the coherence available from an undulator based source to form a microbeam using Fresnel zone-plate optics. The sample is scanned through the beam, and the resulting photoelectron signal correlated with position. With this instrument, we achieved resolution better than 0.3 μm over an energy range of 400 to 700 eV. We also performed some of the first high spatial resolution spectro-microscopy with our first instrument. An improved instrument has subsequently been built at the NSLS, and similar instruments are now found at ALS, ELETTRA, and under construction at SRRC.

Medical Applications of Synchrotron Radiation at the NSLS

W. Thomlinson, "Synchrotron Radiation in the Biosciences," eds. B. Chance, et al, Oxford University Press, New York, 674-680 (1994).

The NSLS is the world leader in breadth of medical research projects and new innovative research programs due to the existence of SMERF and our technical developments of the programs.

Soft X-ray Magneto-Optical Kerr Effect

C.-C. Kao, C.T. Chen, E.D. Johnson, J.B. Hastings, H.J. Lin, G.H. Ho, G. Meigs, J.-M. Brot, S.L. Hulbert, Y.U. Idzerda, C. Vettier, "Dichroic Interference Effects in Circularly Polarized Soft-X-Ray Resonant Magnetic Scattering," Phys. Rev. B ***50,*** *9599 (1994).*

C.-C. Kao, J.B. Hastings, E.D. Johnson, D.P. Siddons, G.C. Smith, G.A. Prinz, "Magnetic Resonant Exchange Scattering at the Fe L_{II} and L_{III} Edges," Phys. Rev. Lett. ***65,*** *373 (1990).*

Dramatic enhancement of the magneto-optical Kerr effect was observed near the L_{II}, L_{III} edges of 3d transition elements and the M_{IV}, M_V edges of rare earth elements using both linearly and circularly polarized soft-x-rays. The element-specific nature of the probe and the enhanced magnetic sensitivity make it an important tool in the study of magnetic thin films and multilayers.

Spin-Polarized Photoemission

P.D. Johnson, N.B. Brookes, S.L. Hulbert, R. Klaffky, A. Clarke, B. Sinkovic, N.V. Smith, R. Celotta, M.H. Kelly, D.T. Pierce, M.R. Scheinfein, B.J. Waclawski, and M.R. Howells, "Spin-Polarized Photoemission Spectroscopy of Magnetic Surfaces Using Undulator Radiation," Rev. Sci. Instrum. 63, 1902 (1992).

Spin-polarized photoemission, in which the spin of electrons photoemitted from the surface of a well-characterized, usually magnetic, solid is measured in addition to their energy and angle, can be further subdivided into core-level or valence-band types. Core-level spin-polarized photoemission is practiced at NSLS by two groups (P. Johnson, BNL Physics and B. Sinkovic, NYU) at various soft x-ray beamlines, but valence-band spin-polarized photoemission is all performed at the purpose-built U5UA beamline. This undulator-based beamline is a unique national resource, providing high flux and high photon energy resolution and a dedicated spin-polarized photoemission end station based on the NIST compact low-energy spin polarimeter. Both the core-level and valence-band programs have produced a wealth of significant results in the area of surface magnetism, including especially the discovery and measurement of surface and interface states in thin film magnetic systems which are at the heart of the magnetic recording industry. For example, one class of experiment at beamline U5UA has examined the development of interfacial magnetism when a noble metal is deposited on a ferromagnetic substrate and the subsequent evolution of interfacial states into spin-polarized quantum well states as the overlayer films become thicker. These studies have provided the first indication that spin polarization effects are present in the non-magnetic layer of the associated magnetic multilayers. Indeed, it is these spin-polarized quantum well states that are thought to mediate the oscillatory exchange coupling in technologically important magnetic multilayers.

Nuclear Forward Scattering

J.B. Hastings, D.P. Siddons, U. van Bürck, R. Hollatz, and U. Bergmann, "Mössbauer Spectroscopy using Synchrotron Radiation," Phys. Rev. Lett. 66, 770 (1991).

For nearly twenty years prior to this work the idea of using synchrotron radiation for Mössbauer spectroscopy had been proposed. This work was the first demonstration of the technique that is now used worldwide to do Mössbauer spectroscopy in the time domain, namely measure the time evolution of the delayed nuclear forward scattering.

The use of high-order Bragg reflections to generate extremely high-resolution beams for various x-ray physics experiments was brought to practical utility at NSLS. The optical layouts and principles embodied in these instruments have been widely emulated. At the time of our NFS experiments (see above) the device used for those measurements was the highest resolving power x-ray monochromator in the world.

Infrared Beamline IR4

*G. P. Williams, "The Initial Scientific Program at the NSLS Infrared Beamline," Nucl. Instrum. Meth. A **291, 8** (1990).*

The development of the infrared beamline U4IR and its scientific program was a unique contribution from the NSLS. The beamline and accelerator scientists worked together to eliminate sources of noise, and the global orbit feedback system played an important role in the success of the infrared program. At the present time many laboratories around the world are planning the development of infrared beamlines based on the success at the NSLS including LURE, France; Daresbury, England; MAX Lab, Sweden; SRRC, Taiwan; ALS, Berkeley; ALADDIN, Wisconsin.

Tunable Linear X-ray Polarimeter

*D. P. Siddons, M. Hart, Y. Amemiya, and J. B. Hastings "X-ray Optical Activity and the Faraday Effect in Cobalt and its Compounds," Phys. Rev. Lett. **64**, 1967 (1990).*

*M. Hart, D.P. Siddons, Y. Amemiya, and V. Stojanoff, "Tunable X-ray Polarimeters for Synchrotron Radiation Sources," Rev. Sci. Instrum. **62**, 2540 (1991).*

This instrument was the first to demonstrate the x-ray Faraday effect in a magnetic metal and x-ray optical activity in a chiral compound. This instrument was also the first x-ray polarimeter with a spectroscopic capability, and was thus able to observe resonance phenomena analogous to those seen in absorption, but with higher sensitivity.

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STORAGE RING ENHANCEMENT

Fourth Harmonic Bunch Lengthening Cavity on VUV Ring

*R. Biscardi, S.L. Kramer, G. Ramirez, "Bunch Length Control in the NSLS VUV Ring," Nucl. Instrum. Meth. A **366**, 26 (1995).*

The lifetime of the electron beam in the VUV Ring is limited by intrabunch Coulomb scattering, and hence is inversely proportional to the bunch density. For high brightness one wants to keep the transverse dimensions of the bunch small, but for most experiments increasing the bunch length is acceptable. The lifetime of the beam in the VUV Ring has been doubled by use of a second RF cavity operating at 211 MHZ, which is the fourth harmonic of the fundamental RF cavity. Stable operation of this system required the development of a novel approach to the control of the phase of the RF waveform.

Small Gap Undulator

P. Stefan, S. Krinsky, G. Rakowsky, and L. Solomon, "Small-Gap Undulator Experiment on the NSLS X-Ray Ring," Proc. 1995 Part. Accel. Conf., Dallas, TX (1995).

Utilizing the small value of the vertical betafunction at the center of the X-Ray Ring insertions, an undulator with a 16cm period has been successfully operated with a vertical electron aperture of only 3 mm with only slight reduction in the beam lifetime. This provides strong support for the belief that small gap undulators will play an important role in the future at synchrotron radiation facilities. Presently, a small gap device is being built in collaboration with SPring-8 in Japan, with the permanent magnet material in the ring vacuum, so that the magnet gap will only be a few hundred microns larger than the beam aperture. This device will be tested in the X-Ray Ring.

Time-varying Elliptically Polarized Wiggler

E. Gluskin, D. Frachon, P.M. Ivanov, J. Maines, E.A. Medvedko, E. Trakhtenberg, L.R. Turner, I. Vasserman, G.I. Erg, Yu.A. Evtushenko, N.G. Gavrilov, G.N. Kulipanov, A.S. Medvedko, S.P. Petrov, V.M. Popik, N.A. Vinokurov, A. Friedman, S. Krinsky, G. Rakowsky, and O. Singh, "The Elliptical Multiple Wiggler Project," Proc. 1995 Part. Accel. Conf., Dallas,TX (1995).

A. Friedman, S. Krinsky and E. Blum, "Polarized Wiggler for the NSLS X-Ray Ring" (1992) BNL-47317.

In collaboration with Argonne and the BINP, Novosibirsk, Russia, an elliptically polarized wiggler has been constructed and operated in the X-Ray Ring with the horizontal wiggler field generated by an electromagnet operated AC to produce radiation with a time-varying circular polarized component. The AC elliptically polarized wiggler makes it possible to detect the very weak signatures of circular dichroism and other effects associated with right versus left handedness of some physical systems. The key technical challenge, which was successfully met, was to oscillate the horizontal wiggler field without moving the electron beam and disturbing any of the experimenters using other beamlines around the X-Ray Ring. At 2 Hz, a residual orbit motion of less than 0.5 micron has been observed, and the device has run several months in regular X-Ray operations without complaint from other users. We are now working to achieve 100 Hz operation of the wiggler.

Beam Based Storage Ring Lattice Modeling

J. Safranek, "Experimental Determination of Linear Optics Including Quadrupole Rotations," Proc. 1995 Part. Accel. Conf, Dallas,TX (1995).

This approach uses the very precise orbit measurements now available, to calibrate the mathematical model of the storage ring. In the X-Ray this method has been used to reduce the horizontal and vertical emittances. It has been employed at the ALS at Berkeley to eliminate a beta-beat caused by variation in the strength of the defocusing quadrupoles. There are plans to use this program at MAXLAB, SPEAR, ALLADIN and APS.

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THEORETICAL WORK ON PHOTON SOURCES

Theory of Short Wavelength FEL Amplifiers

Proposal for the DUV Free Electron Laser (1994) BNL 49713

L.H. Yu, S. Krinsky, R. L. Gluckstern and J.B.J. van Zeijts, "The Effect of Wiggler Errors on FEL Gain," Phys. Rev. A 45, 1163 (1992).

L.H. Yu, "Generation of Intense UV Radiation by Subharmonically Seeded Single Pass FEL," Phys. Rev. A 44, 5178 (1991).

I. Ben-Zvi, L.F. Di Mauro, S. Krinsky, M.G. White, and L.H. Yu, "Proposed UV-FEL User Facility at BNL," Nucl. Instrum. Meth. A 304, 181 (1991).

L. H. Yu, S. Krinsky and R.L Gluckstern, "Calculation of Universal Scaling Function for FEL Gain," Phys. Rev. Lett. 64, 3011 (1990).

S. Krinsky, "Introduction to the Theory of Free Electron Lasers," AIP Conf. Proc. 153, 1015 (1987).

J.M. Wang and L.H. Yu, "A Transient Analysis of a Bunched Beam Free Electron Laser," Nucl. Instrum. Meth. A 250, 484 (1986).
S. Krinsky and L.H. Yu, "Output Power in Guided Modes for Single Pass Free Electron Laser Starting from Shot Noise," Phys. Rev. 35, 3406 (1985).
R. Bonifacio, C. Pelligrini, and L.M. Narducci, "Collective Instabilities and High-gain Regime in a Free Electron Laser," Opt. Commun. 50, 373 (1984).
There has been a continuing effort to develop the theory underlying short wavelength free electron laser amplifiers. Above is given a selection of the key publications resulting from the work at the NSLS. Subjects covered include: description of the high gain exponential growth regime, self amplified spontaneous radiation, effect of electron beam quality on gain, gain reduction due to wiggler errors, subharmonically seeded FELs, proposal for a user facility utilizing subharmonically seeded FELs. A large scale experiment to study short wavelength FEL amplifiers is under construction at the TESLA facility at DESY, Germany. At Brookhaven we are working to carry out experiments on FEL amplifiers at the Accelerator Test Facility and the Source Development Laboratory.

Theory of Undulator Radiation
S. Krinsky, "Undulators as Sources of Synchrotron Radiation," IEEE Trans. Nucl. Sci. NS-30, 3083 (1983).
M.R. Howells, J. Kirz, and S. Krinsky, "A Beamline for Experiments with Coherent Soft X-rays," (1982) BNL-32519.
An analysis of undulator radiation was carried out which showed that low-beta insertions were suitable locations for these devices. This led to the development of the soft x-ray undulator in the X1 straight section of the X-Ray Ring. The relatively large horizontal angular spread does not degrade the brightness, but does allow splitting the undulator beam to illuminate three separate experiments.

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X-RAY OPTICS

X-ray Schlieren Imaging
D. Chapman, W. Thomlinson, and Z. Zhong (to be published).
A new x-ray technique applied to mammographic imaging. Separation of the absorption image and index of refraction image should provide additional information to the mammographers about various tumors.

Collimating Mirrors for X-ray Beamlines
J.B. Hastings, "NSLS EXAFS Beamline Design," BNL Informal Report BNL-30617.
In general at typical x-ray synchrotron sources the vertical opening angle of the bending magnet radiation is greater than the intrinsic width of typical perfect crystal rocking curves. In order to maintain high throughput and improve the energy resolution of standard two-crystal instruments the use of an x-ray collimating mirror was proposed followed by the monochromator and then a condensing optic to provide a small focus at the sample position. This idea was executed at X19 and has proven very successful, reducing the bandwidth of the monochromator by almost a factor of three with very little loss in intensity.

High Resolution Bent-Crystal Analyzers

*K. Hämäläinen, M. Krisch, F. Sette, C.-C. Kao, W. Caliebe, J.B. Hastings, "High Resolution X-ray Spectrometer Based on a Cylindrically Bent Crystal in Nondispersive Geometry," Rev. Sci. Instrum. **66**, 1525 (1995).*

*V. Stojanoff, K. Hämäläinen, D.P. Siddons, J.B. Hastings, L.E. Berman, S. Cramer, G. Smith, "A High-resolution X-ray Fluorescence Spectrometer for Near Edge Absorption Studies," Rev. Sci. Instrum. **63**, 1125 (1992).*

Spherically and cylindrically bent crystal analyzers with large solid angle acceptance were developed for inelastic x-ray scattering experiments. These analyzers can also be used in high resolution fluorescence analysis and fluorescence yield x-ray absorption spectroscopy. Multi-element analyzer array is being developed at the moment.

High Resolution Inelastic X-ray Scattering

C.-C. Kao, W.A. Caliebe, K. Hämäläinen, M. Krisch, J.B. Hastings, "The Studies at the Inelastic Scattering Beamline at the NSLS," National Conference on Synchrotron Radiation Instrumentation 1995, Argonne National Laboratory, October 17-20 1995. Rev. Sci. Instrum. (to be published).

The inelastic x-ray scattering program is focused on the study of elementary electronic excitations in condensed matters. In comparison with other inelastic scattering probes, such as light scattering and neutron scattering, inelastic x-ray scattering is unique in providing frequency- and wavevector-dependent dielectric responses of materials.

Optimized Beamline for Low Energy (2-8 keV) Spectroscopy Techniques

L.R. Furenlid, P.E. Stefan, and J.B. Hastings, 5th International Conference on Synchrotron Radiation Instrumentation, Stony Brook, NY, 1994 (unpublished).

Beamline X19A has been developed through a series of R&D projects to optimize the transport, monochromatization, and detection of x-rays in the 2-8 keV domain. Key components include a full collimating mirror/focussing mirror arrangement for optimum resolution and intensity; an 8 = μm Be foil thin window and associated fast shutter system; a horizontal feedback system to keep beam position constant on the sample; triple bounce monochromator crystals for superior rejection of harmonics via detuning; a high performance, high stability UHV monochromator with external drive componentry; a modular, kwik flange based sample holder and cryostat system for rapid setup of air excluded beam paths, and low energy ion-chamber detectors.

High Power Diamond Crystal X-ray Monochromator

L.E. Berman, J.B. Hastings, D.P. Siddons, M. Koike, V. Stojanoff and M. Hart, "Diamond Crystal X-ray Optics for High-power-density Synchrotron Radiation Beams," Nuclear Instruments and Methods in Physics Research A 329, 555 (1993).

L.E. Berman and M. Hart, "Preserving the High Finesse of X-ray Undulator Beams from Perfect Water-jet-cooled Diamond Monochromators," Nuclear Instruments and Methods in Physics Research A 334, 617 (1993).

Radiated x-ray power densities at present and future synchrotron radiation sources are unprecedented, and cannot be tolerated by conventional silicon and germanium crystal monochromators designed to diffract x-rays efficiently and simultaneously preserve the ray optics

of the primary beam, when used at room temperature. Single crystal diamond is an attractive alternative to silicon and germanium as a room temperature x-ray monochromator, because of its substantially superior mechanical and thermal properties, foremost among them being an exceptionally high thermal conductivity. Experiments performed at X25 have proven the efficacy of diamond as a high-power-density x-ray monochromator material, with its implementation as such carried out in a relatively simple and inexpensive manner. This bodes well for the highest power beam lines being commissioned at the newer sources such as the APS, where plans to use diamond monochromators are being pursued.

Adaptive Silicon Crystal X-ray Monochromators

L.E. Berman and J.B. Hastings, "An adaptive Crystal Bender for High Power Synchrotron Radiation Beams," Proc. SPIE 1739, 489 (1993).

L.E. Berman, M. Hart, and S. Sharma, "Adaptive Crystal Optics for Undulator Beamlines," Nucl. Instr. and Meth. A 321, 617 (1992).

L.E. Berman and M. Hart, "Adaptive Crystal Optics for High Power Synchrotron Sources," Nucl. Inst. and Meth. A 302, 558 (1991).

A foremost challenge to proper operation of an x-ray monochromator in a high power x-ray beam, lies in eliminating the crystal Bragg plane strains arising from thermal distortion, which reduce the diffraction efficiency and spoil the beam brightness. A major research program at beam line X25 has been undertaken to study this, with implicit benefits for existing high power beam lines such as X25, as well as for future ones such as those under construction at the APS. A solution, which has been adopted for the X25 beam line monochromator, involves adaptive mechanical compensation of the thermal strain field. This is centered on the use of a bendable triangular silicon wafer that is thermally coupled to a cooled heat sink via a liquid metal interface. Tests and use have demonstrated that this device faithfully delivers the intrinsic x-ray beam brightness at X25.

X-ray Optical Delay Line.

S. Joksch, W. Graeff, J.B. Hastings, and D.P. Siddons, "Performance of an X-ray Optical Delay Line with Synchrotron Radiation," Rev. Sci. Instrum. 63, 1114 (1992).

An optical delay line for x-rays was demonstrated which can deliver a monochromatic beam with a variable delay following illumination of the sample with the broad band SR spectrum. This is a technique that should find usefulness in a wide variety of pump probe experiments where statistical significance can be acquired through cyclic excitation.

High Energy, High Q-resolution X-ray Scattering

J.B. Hastings and D.P. Siddons, "The Use of High Energy Synchrotron Radiation for X-ray Scattering," Proc. of 2nd European Conf. on Progress in X-ray Synchrotron Radiation Research, A. Balerna, E. Bernieri, and S. Mobilio, Eds., Vol. 25, p. 159, SIF, Bologna (1990).

The use of high energy x-rays for a broad range of x-ray scattering experiments is summarized. This work describes research started in collaboration with Dr. Jochen Schneider from HASYLAB. Both our group and a team at HASYLAB have continued to pursue this effort and it has expanded to include beamlines at ESRF and SPring-8.

Mosaic Crystal Two-crystal Monochromator

*D. Hohlwein, D.P. Siddons, and J.B. Hastings, "A Graphite Double Crystal Monochromator for X-ray Synchrotron Radiation," J. Appl. Cryst. **21**, 911 (1988).*

A two crystal monochromator utilizing mosaic graphite crystals was constructed. It provides a significant increase in bandwidth and intensity when compared with typical perfect crystal instruments. Furthermore, in the two crystal arrangement, the mosaic spread only contributes to an increase in the divergence in the non-Bragg direction. This idea will be useful in a variety of quasi-monochromatic x-ray techniques including diffuse scattering and various film techniques applied to structure solution.

Fluorescence Detection for Low-Z X-ray Spectroscopy

*J. Stöhr, E.B. Kollin, D.A. Fischer, J.B. Hastings, F. Zaera, and F. Sette, "Surface Extended X-ray Absorption Fine Structure of Low Z Adsorbates Studied with Fluorescence Detection," Phys. Rev. Lett. **55**, 1468 (1985).*

This work demonstrated the efficacy of using fluorescence detection for low z x-ray spectroscopy. Prior to this work electron detection was thought to be the only viable measure of the variation in absorption for low z-materials. Application of fluorescence detection has opened the field of x-ray spectroscopy to low z elements in non UHV environments.

High-Resolution Synchrotron Powder Diffraction

*J.B. Hastings, W. Thomlinson, and D.E. Cox, "Synchrotron X-ray Powder Diffraction," J. Appl. Cryst. **17**, 85 (1984).*

The use of crystal analyzers for monochromatic SR powder diffraction is presented in detail including all the advantages of their use. Also, the detailed analysis of measured peak shapes is presented. This contribution has lead to the worldwide use of crystal analyzers for high resolution SR powder diffraction.

Kirkpatrick-Baez Multilayer Optics for an X-ray Microprobe

*M.R. Howells and J.B. Hastings, "Design Considerations for an X-ray Microprobe," NIM **208**, 379 (1983).*

Design considerations for an x-ray microprobe were presented and the conclusion drawn that the most effective instrument would be a Kirkpatrick-Baez mirror pair where the reflecting optics were coated with multilayers. This choice provides the best compromise of large demagnification and quasi-monochromaticity. The idea has been executed by several groups including people from LBNL.

Sagittally Focusing Crystal Monochromators

*C. Sparks, B. Borie, J.B. Hastings. "X-ray Monochromator Geometry for Focusing Synchrotron Radiation above 10 KeV," NIM **172**, 237 (1980).*

The concept of using crystals to do sagittal focusing was presented. The optimal position of the monochromator was discussed giving the 3:1 position as that of choice. Detailed calculations of collection efficiency were presented. This paper is the basis for all sagittal focusing systems presently in use at synchrotron sources.

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ULTRA VIOLET OPTICS

Economical Upgrade Path for Outdated Toroidal Grating Monochromators.
N. V. Smith, S. L. Hulbert, P. D. Johnson, and J. L. Erskine, "Spherical-grating Monochromator System with Circular-polarization Capability for the U5U Undulator at Brookhaven," Nucl. Instrum. & Methods A 347, 119 (1994).
It has been shown that out-of-date soft x-ray toroidal grating monochromators (TGMs) can be efficiently, and therefore cheaply, upgraded to state-of-the-art spherical grating monochromators (SGMs) by replacing only the reflecting and diffracting optical elements. In most cases, the collecting and focusing functions in these beamlines are provided by a single mirror, usually of toroidal figure. An appropriate replacement toroid, near unity magnification, can provide the same throughput as the "standard" Kirkpatrick-Baez mirror pair. The new resulting beamline, dubbed TSGM for toroidal-mirror SGM, provides photon energy resolution and flux equal to the "standard" SGM configuration, and can fit in substantially less floor space since it has no horizontal deflections.

UHV Compatible Two-Crystal Monochromator.
*P. Cowan, J.B. Hastings, T. Jach, and J. Kirkland, "A UHV Compatible Two-Crystal Monochromator for Synchrotron Radiation," NIM **208**, 349 (1983).*
J. Golovchenko and co-workers had developed a mechanical coupling to provide a constant offset wide angular range two crystal x-ray monochromator. This mechanical design was adapted to a UHV environment. Several innovations were made, including a UHV-compatible long-stroke piezo translator. These instruments are used in several locations on the x-ray floor and remain the most functional of all designs to date for this application. It is of particular importance for x-ray energies below 4 KeV.

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INFRA RED OPTICS

Research on the First Infrared Beamlines
F.M. Hoffmann, B.N.J. Persson, W. Walter, D.A. King, C.J. Hirschmugl, and G.P. Williams, "Anti-absorption Resonances in the Infrared Reflectance Spectroscopy of Alkali-Cu(111) Adsorbate Systems," Phys. Rev. Lett. 72, 1256 (1994).
R.J. Hemley, Z.G. Soos, M. Hanfland, and H.-K. Mao, "Charge Transfer States in Dense Hydrogen," Nature 369, 384 (1994).
C. Meade, J.A. Reffner, and E. Ito, "Synchrotron Infrared Absorbency Measurements of Hydrogen in $MgSiO_3$ Perovskite," Science 264, 1558 (1994).
G.L. Carr, M. Quijada, D.B. Tanner, C.J. Hirschmugl, G.P. Williams, S. Etemad, B. Dutta, F. DeRosa, and T. Venkatesan, "Fast Bolometric Response by High T_c Detectors Measured with Subnanosecond Synchrotron Radiation," Appl. Phys. Lett. 57, 2725 (1990).
L. Forro, G.L. Carr, G.P. Williams, D. Mandrus, L. Mihaly, "Far Infrared Transmission Study of Single Crystal $Bi_2Sr_2Ca_2Cu_2O_x$" Phys. Rev. Lett. 65, 1941 (1990).
The U4IR beamline was the first infrared beamline developed on the NSLS VUV Ring. The scientific program was directed toward far infrared spectroscopy of adsorbates on metal surfaces;

a model system for exploring the surface physics and chemistry that control catalysis as well as other phenomena. This program determined the importance of interactions between adsorbed atoms and conduction electrons. Other scientific investigations include the first (and only) far infrared spectra of free-standing high-T_c cuprate crystals, and demonstrations of time-resolved measurements (such as pump-probe spectroscopy) that utilize the synchrotron's pulse structure.

The U2B beamline enables high brightness spectroscopy in the mid-infrared. It is used for microspectroscopy studies of materials at extremely high pressures (i.e. geo-physical sciences) and for micro-analysis of materials such as semiconductors, polymers, ceramic composites, biological cells, and even forensics. As a result of a CRADA between the NSLS and the Northop-Grumman Corporation, the NSLS was able to initiate construction on two new infrared beamlines (U12IR and U10), optimized for microspectroscopy and very far infrared spectroscopy.

Lamellar-grating IR Interferometer

K.D. Moeller, T. Sears, H.T. Liu, C.J. Hirschmugl, and G.P. Williams, "A High Resolution Interferometer for use with Synchrotron Radiation," Nucl. Instr. Meth. Phys. Res. A319, 250 (1992).
K.D. Moeller, D.P. Siddons, C.J. Hirschmugl, D. Scardino, P. Petrone, D. Carlson, and G.P. Williams, "Two Mirror Wavefront Dividing Interferometer for Infrared Synchrotron Radiation," Appl. Optics 30, 4297 (1991).

The lamellar grating interferometer is a spectrometer optimized for performance in the very far infrared (wavelengths beyond 100 microns); the region where the NSLS VUV Ring outperforms the standard far IR spectrometer source (the high pressure mercury arc lamp) in both brightness and flux. This is an important spectral range for investigating metals, semiconductors and superconductors, including the "bad metals" which are the central theme of the new joint research initiative between the physics department and the NSLS. The high degree of transverse coherence to the NSLS source enabled a highly efficient, wide-spectral range, wave-front dividing interferometer to be built and demonstrated. The high degree of transverse coherence inherent in synchrotron IR radiation permitted a very simple interferometer design capable of operation over a very large wavelength range. The coherence properties meant that the wavefront could be divided into only two parts (rather than the 20-100 parts used in conventional LGI's). These parts could, therefore, be made of high quality quite easily, thus the coherence could be maintained up to quite short wavelengths (a few microns). The long wavelength limit is diffraction driven at about 5 mm. Key to the advantages of this instrument is its lack of a beamsplitter; essential if such a wide spectral range is to be probed.

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CONSTRUCTION AND OPERATION OF THE BNL ACCELERATOR TEST FACILITY: A USER FACILITY FOR THE PHYSICS OF BEAMS

The BNL Accelerator Test Facility (ATF) is this country's only proposal-driven, peer-reviewed user's-facility for accelerator and beam physics, including studies in the generation of high-brightness electron-beams, Free-Electron Laser experiments and many others. Milestone experiments at the ATF include:

Inverse FEL Acceleration of Electrons
A. van Steenbergen, J. Gallardo, J. Sandweiss, J.-M. Fang, "Observation of Energy Gain at the BNL Inverse Free-Electron Laser," Phys. Rev. Lett. (to be published).

Generation of Femtosecond Pulses of High-brightness Electrons
X.J. Wang, X. Qiu and I. Ben-Zvi, "Experimental Observation of High-Brightness Micro-Bunching in a Photocathode RF Gun," Phys. Rev. Lett. (submitted).
Electron beam bunches with an extremely high brightness have been produced by the BNL gun at the ATF, from a nanoCoulomb at 10 picosecond FWHM with rms normalized emittance of 4 mm mrad to 40 picoCoulomb at 0.4 picosecond FW and 0.5 mm mrad.

Slice Emittance Measurement
X. Qiu, K. Batchelor, I. Ben-Zvi and X.J. Wang, "Demonstration of Emittance Compensation Through the Measurement of the Slice Emittance of a 10 Picosecond Electron Bunch," Phys. Rev. Lett. 76, 3723 (1996).
This electron beam diagnostic technique makes it possible to study the phase space of the electron beam in 6-D phase space with picosecond resolution. It is an essential element for further improvement of electron beam brightness.

Inverse Cherenkov Acceleration of Electrons
W.D. Kimura, G.H. Kim, R.D. Romea, L.C. Steinhauer, I.V. Pogorelsky, K.P. Kusche, R.C. Fernow, X.J. Wang and Y. Liu, "Inverse Cerenkov Acceleration of Electrons by 3.7 MeV using 580 MW of the ATF's CO_2 Laser," Phys. Rev. Lett. 74, 546 (1995).

High-upshift, Forward Angle Smith-Purcell Radiation Measurement
K.J. Woods, J.E. Walsh, R.E. Stoner, H.G. Kirk, R.C. Fernow, "Forward Directed Smith-Purcell Radiation from Relativistic Electrons," Phys. Rev. Lett. 74, 3808 (1995).

Development of the High Gain Harmonic Generation FEL
High-Gain Harmonic-Generation (HGHG) FEL has been developed at BNL's NSLS as a method to achieve UV and x-ray coherent and tunable radiation with a high peak-power, narrow bandwidth, high-stability and single pass amplifier approach.

Chirped-pulse Amplification with HGHG FEL

*L.-H. Yu, E. Johnson, D. Li and D. Umstadter, "Femptosecond Free-electron Laser by Chirped Pulse Amplification," Phys. Rev. E **49**, No. 5, 4480 (1994).*

Development of a Multiple-function Superconducting-undulator

G. Ingold, I. Ben-Zvi, S. Krinsky, D. Lynch, J. Sheehan, L. Solomon, M. Woodle, L. Yu, X. Zhang, W. Sampson, K. Robins, I. Lehrman, R. Heuer, J. Sheehan, D. Weissenburger, "A Superconducting Short Period Undulator for a Harmonic Generation FEL Experiment," Proceedings 1993 Particle Accelerator Conference, Washington DC, May 17-20, (1993).

'Fresh-Bunch' Technique

*I. Ben-Zvi, K.M. Yang and L.H. Yu, "The 'Fresh-Bunch' Technique in FELs," Nuclear Instruments & Methods in Physics Research A **318**, 726 (1992).*

A Proof-of Principle experiment in High Gain Harmonic Generation

*I. Ben-Zvi, A. Friedman, C.M. Hung, G. Ingold, S. Krinsky, L.H. Yu, I. Lehrman and D. Weissenburger, "Design of a Harmonic Generation FEL Experiment at BNL," Nuclear Instruments & Methods in Physics Research A **318**, 208 (1992)*

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ACHIEVEMENTS IN TECHNOLOGY AND ENGINEERING

NSLS-DAC: A Flexible Beamline Control Program

L.R. Furenlid, A. Mayer, and J. Kirkland, "NSLS-DAC: A Flexible Beamline Control Program," Journal de Physique (submitted).

Synchrotron beamline control software was developed in the last year and implemented on the experimental floor on XAS beamlines U7, X11A, X18B, X19A, and X23B. It is currently being implemented on beamline X9B, and in the near future on X23A2. This software presents the novice as well as experienced researchers with an intuitive, graphical-user-interface environment for a full complement of experimental techniques. Though the software is geared for spectroscopy, a full macro capability and the inclusion of calls to user supplied external routines accommodate general purpose data collection. The establishment of this software as a standard on the XAS beamlines on the experimental floor is already resulting in a significant reduction in the resources spent on user training and enhancing experiment quality.

Very High Aspect Ratio and 3-dimensional Micromachining Using Hard X-rays

*E.D. Johnson, J.C. Milne, D.P. Siddons, H. Guckel, and J.L. Klein, "Precision Machining with Hard X-rays: Experiments at the NSLS," Synchrotron Radiation News **9**, no. 4, 10 (1996).*

*D.P. Siddons, E.D. Johnson and H. Guckel, "Precision Machining Using Hard X-rays," Synchrotron Radiation News **7**, 16, (1994).*

At the NSLS, we initiated a program to explore the features of lithography utilizing hard x-rays with the aim of developing methods for the very precise manufacture of macroscopic, three-dimensional

structures. We have demonstrated lithographic processing of resist materials to the scale of several centimeters while maintaining precision at the level of microns. This technology allows complex 3-dimensional objects to be machined with sub-micron precision. A production beamline is being constructed based on this work, and on the substantial interest from companies who want to use hard x-ray lithography for manufacturing products.

Multielement Solid State Detector

A. Pullia, L. Furenlid, H.W. Kraner, G. Bertuccio, P.J. Pietraski, and D.P. Siddons, "Multielement Solid State Detector," Rev. Sci. Instrum. (in press).

A multielement detector has been developed for x-ray absorption spectroscopy and diffraction applications at the NSLS. The front end, developed in collaboration with the Instrumentation Division, comprises a silicon wafer based pixel detector and an array of charge sensitive preamplifiers. Powerful NIM-bin based modules based on field programmable gate arrays and modular circuit inserts handle all subsequent signal processing under complete computer control. A significant scientific and engineering effort has lead to outstanding resolution performance. The instrument has been proven in prototype form and is now in a manufacturing stage.

Development of RF Guns, Photocathode Materials and Diagnostic Techniques

X.J. Wang and I. Ben-Zvi, High-Brightness Electron Beam Diagnostics at the ATF, Proc. Beam Instrumentation Workshop, Argonne National Lab., May 6-8, 1996. BNL 63151.

X.J. Wang, T. Srinivasan-Rao, K. Batchelor, I. Ben-Zvi and J. Fischer, "Measurements on Photoelectrons from a Magnesium Cathode in a Microwave Electron Gun," Nuclear Instruments and Methods in Physics Research A 356, 159 (1995).

MacXAFS: An EXAFS Analysis Package for the Macintosh

C. Bouldin, W.T. Elam, and L.R. Furenlid, "MacXAFS: An EXAFS Analysis Package for the Macintosh," Physica B 208&209, 190 (1995).

An analysis package for x-ray absorption spectroscopy was developed to permit real-time analysis during data acquisition, as well as full, documented work for publication. A front-end application which presents a unified interface ties together well tested numerical algorithms for data normalization, background subtraction, Fourier analysis, non-linear least squares fitting, and ab-initio modeling. The package has a world-wide user base numbering in the hundreds.

Testing of APS Vacuum Chambers

C.L. Foerster, C. Lanni, J.R. Noonan and R.A. Rosenberg, "Photon Stimulated Desorption Measurement of an Extruded Aluminum Beam Chamber for the Advanced Photon Source," 42nd National Symposium of Amer. Vac. Soc., Oct. 1995.

PSD measurement on X28A beamline of an extruded aluminum APS storage ring chamber. The data was used by ANL to evaluate chamber construction and preparation.

High Stability, High Power Nd:YAG Laser for Photocathode Illumination

M. Babzien, I. Ben-Zvi, J. Fischer, A.S. Fisher, K. Kusche, I.V. Pogorelsky, T. Srinivasan-Rao, "A High Power Picosecond Nd:YAG/CO_2 Laser System for Electron Guns, Laser Acceleration and FEL," Proc. of Lasers '94 Conference, Quebec, Canada, Dec. 12-16, 1994. BNL 61399. Feb. 1995.

High Power, Picosecond Pulse CO_2 Laser
I. Pogorelsky, W.D. Kimura, C.H. Fisher, F. Kannari, N.A. Kurnit, "Approach to Compact Terawatt CO_2 Laser System for Particle Acceleration." Presented at the 6th Workshop on Advanced Accelerator Concepts, Lake Geneva, Wisconsin, June 12-18, 1994. BNL 60826.

Non-linear, Non-instantaneous Adaptive Feed-forward Control System for Linac Energy
R. Zhang, I. Ben-Zvi and J. Xie, "A Self-Adaptive Feed-forward RF Control System for Linacs," Nuclear Instruments and Methods in Physics Research A 324, 421 (1993).

Copper Chamber Desorption Measurements
C.L. Foerster, H. Halama, G. Korn, M. Calderon and W. Barletta, "Desorption Measurements of Copper and Copper Alloys For PEP II," Vacuum, 44(5-7), 489 (1993).
PSD measurements of copper and its alloys for PEP II. Neutral gas, photo electron and scattered photon data taken on beamline U10B. PEP II prototype copper chamber was tested on X28A beamline. Work supported by LLNL and SLAC.

Compact UHV Valve with Field Replaceable Windows
E.D. Johnson, J. Freeman, F. Powell, "Compact UHV Valve with Field Replaceable Windows," Rev. Sci. Instrum. 63,1282 (1992).
There are many applications in synchrotron radiation research where window valves can be usefully employed. Examples include gas cells for monochromator calibration, filters for high-order light rejection, and as vacuum isolation elements between machine and experimental vacua. We took advantage of a new valve seal geometry developed by VAT corporation to make a simple removable window insert in a gate valve sealing plate. The window design was similarly based on a standard geometry available from Luxel Corporation. Working together, we developed what has become a very popular commercial product for both companies, and a high quality, modest cost device for use at many synchrotrons. At present, there are several hundred of these valves in service.

Bittner-Biscardi Receiver for Beam Position Monitor
R. Biscardi and J.W. Bittner, "Switched Detector for Beam Position Monitor," IEEE Proc. 1989 Part. Accel. Conf., Chicago, IL, Vol. III, p. 1516 (1989)
This high precision receiver forms the basis for orbit measurement and control at the NSLS. Duke University FEL Laboratory, ALS at Berkeley, and APS at Argonne plan to use receivers based on this design for all of or a subset of their orbit measurements.

High-Power Ultra-High Vacuum (UHV) Photon Beam Position Monitor
E.D. Johnson and T. Oversluizen, "Compact High Flux Photon Beam Position Monitor," Rev. Sci. Instrum. 60, 1947 (1989).
In synchrotron radiation sources, from the standpoint of the users, *photon beam stability* is vital for the realization of state of the art research. This is particularly true for undulator beamlines where due to the brightness of the source, small shifts in beam position can result in unacceptable intensity and energy fluctuations. Reliable measurement of the photon beam position is necessary to apply stabilization techniques. Prior to this research, no such device existed. The monitor utilizes electrically isolated blades introduced into the edge of the beam. Schemes such as this had been tried before, without success. In our case, a geometry was developed which stabilized the positions

of the blades, provided electrical isolation with significant cooling, and embodied an efficient collection geometry for the photoelectrons generated from the blades. This device achieved sub-micron resolution, and has been the acknowledged model for similar instruments placed in *all* of the third generation machines, world wide.

UHV Synchrotron Radiation Pumped Absorber

C.L. Foerster, T.S. Chou H. Halama, and C. Lanni, "Measurements of a Prototype Synchrotron Radiation Pumped Absorber For Future Light Sources," AIP Conf. Proc. ***171****, 334 (1988).*

Measurements were made at NSLS U10B beamline as joint effort of NSLS and LBNL. The concept was used for the ALS at LBNL.

In Situ Reactive Cleaning of X-ray Optics by Glow Discharge

E.D. Johnson and R.F. Garrett, "In Situ Reactive Cleaning of X-ray Optics by Glow Discharge," Nucl. Instrum. & Meth. A ***266,*** *381 (1988).*

E.D. Johnson, S.L. Hulbert, R.F. Garrett, G.P. Williams, and M.L. Knotek, "In Situ Reactive Glow Discharge Cleaning of X-ray Optical Surfaces," Rev. Sci. Instrum. ***58,*** *1042 (1987).*

In soft x-ray monochromators, particularly at synchrotron radiation facilities, carbon contamination can severely limit the throughput and resolution of the instrument, even for wavelengths far away from the carbon K edge. We developed a method of in-situ cleaning using RF glow discharges which is capable of complete removal of carbon contamination. The various reactors developed at the NSLS are quite simple, and have been retrofitted to a variety of instruments. The results achieved are far superior, and require significantly less time to obtain than with conventional cleaning methods. This technology, our reactor design, and process method have been adopted at essentially every soft x-ray synchrotron facility in the world.

Demountable UHV Beryllium Window

T. Oversluizen and P. M. Stefan, "Replaceable Be and Al Windows for X-ray Beamlines," Nucl. Instrum. & Meth. A ***266,*** *375 (1988).*

Beryllium windows are essential for a wide range of x-ray apparatus. The standard technology for UHV compatible windows was to vacuum-braze the beryllium wafer into a copper or stainless steel assembly. This process is expensive and inflexible. T. Oversluizen devised a scheme which used soft metal compression seals to capture the beryllium in a stainless steel flange assembly. Thus, the window could be easily replaced if damaged, or remounted into a different assembly if the experiment needs changed. Such a flange assembly is inexpensive to produce, and the beryllium material can be standard sizes, allowing ready production of custom window assemblies.

A Program for Synchrotron Radiation Dose Calculations

D. Chapman, N. Gmür, N. Lazarz and W. Thomlinson, "PHOTON: A Program for Synchrotron Radiation Dose Calculations,". Nucl. Instrum. and Meth. A ***266,*** *191 (1988).*

A user friendly program to calculate dose from scattered and direct photon beams through arbitrary absorbers and storage ring. It has been copied (and much improved) by other labs as well as by our staff.

Measurement of Photon Stimulated Desorption of NSLS Beam Chamber

H.J. Halama, C. Foerster, and T. Kobari, "Vacuum Performance of the UV and X-Ray Rings at the NSLS," J. Vac. Sci. Technol., A 5 (4), 2342 (1987).

Measurements of PSD in a NSLS aluminum vacuum chamber. The data was used to design new higher power beam chambers by the NSLS, BNL and other laboratories worldwide.

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Measurements of PSD in a NSLS aluminum vacuum chamber. The data was used to design new higher power beam chambers by the NSLS, BNL and other laboratories worldwide.

Fast Valve Protection System
C. Foerster and R. Larson, "Evaluation of NSLS Beamline Fast Valve Protection System," J. Vac. Sci. Technol., A 5 (4), 2401 (1987).
This valve was designed and built by BNL (T. Oversluizen). Response time, shockwave effects and vacuum sealing were tested to establish beamline protection needs and vacuum sensor locations. The NSLS design was used by Vacuum Generators Ltd. for their fast valve product line.

High Flux Photon Beam Monitor
P. Mortazavi, M.H. Woodle, H. Rarback, D. Shu, and M. Howells, paper SRI Mtg Stanford, CA (1985).
The device first used heatpipes to transport absorbed heat from detector blades to heat exchanger. Eliminated waterflow vibrations at detector and risk of water to UHV leak.

Fast Vacuum Valve for Vacuum Safety
T. Oversluizen, "Fast Valve for the National Synchrotron Light Source," Nucl. Instrum. & Meth. 195, 399 (1982).
The need for all-vacuum beamlines with minimal vacuum protection from thick windows prompted this design, which extends the time for the shock-wave produced by a vacuum accident at the end-station to propagate to the storage ring chamber, thus allowing a fast-acting shutter to close in time to protect the ring vacuum.

Development of In-vacuum Sliding Electrical Contacts
Work done by P. Mortazavi for 52 MHZ RF Cavity Tuners, (1982).
The reliability of sliding electrical contacts in vacuum had been a significant problem. A custom spring finger design was developed which has reliably operated for years in the NSLS RF cavity tuners.

Development of Helicoflex Seal for NSLS 52 MHZ RF Cavities
Work done by P. Mortazavi resulted in a reliable UHV vacuum seal for the RF Cavity cover which allowed frequency tuning of the cavity by virtue of seal deflection while maintaining vacuum tightness.

Optical Metrology: 1993 R&D 100 Award
The collaboration between P.Z. Takacs and E. Church produced what has become the standard description of figure and finish in the optics industry. Previously the standards were extremely qualitative, using ill-defined terms such as "scratch" and "dig." Application of high-resolution optical interferometry and Fourier analysis of the results has led to international standards bodies adopting their descriptions of surface figure and finish. The industry standard instrument for measuring surface figure in large optics (the Long-trace Profilometer) was developed in the BNL Instrumentation Department by P. Takacs and funded by the NSLS.

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HIGH BRIGHTNESS ELECTRON BEAMS

Development of High Brightness Electron Beams

X.J. Wang, T. Srinivasan, K. Batchelor, M. Babzien, I. Ben-Zvi, R. Malone, I. Pogorelsky, X. Qiu, J. Skaritka and J. Sheehan, "Experimental Characterization of High-Brightness Electron Photoinjector," Nuclear Instruments and Methods in Physics Research A 375, 82 (1996).

Electron beams with a high density of electrons in 6-D phase space are the keystone for future high performance machines such as X-ray Free-Electron Lasers and linear colliders. The BNL S-band photocathode RF gun has been adopted for use by many laboratories and industries; notably: BNL ATF, SDL and CRCR, CERN, Japanese Laboratory for High-Energy Physics, Northrop-Grumman Corporation, Rocketdyne Corporation, Stanford Linear Accelerator Center, University of California at Los Angeles. The robust metal photocathode for RF guns has been developed at BNL. BNL-developed guns have achieved a record peak-surface-electric-field (150 MV/m).

BNL RF Photocathode Electron Gun

K. Batchelor, H. Kirk, J. Sheehan, M. Woodle, and K. McDonald, "Development of a High Brightness Electron Gun for the Accelerator Test Facility," European Particle Accelerator Conference (1988).

Describes the design and testing of the first generation of the BNL design RF Photocathode Electron Gun. Derivative designs used at CERN, SLAC, UCLA , KEK and elsewhere.