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BROOKHAVEN NATIONAL LABORATORY

National Synchrotron Light Source: Big Machine, Big Results

X-rays were discovered in 1895. Now, almost 100 years later, x-rays, along with ultraviolet light and infrared radiation, are among the most important tools for basic and applied research.

BNL's National Synchrotron Light Source (NSLS), which was commissioned in 1982, is one of the first electron storage rings dedicated solely to generating synchrotron light for use as probes in science. This special edition of the Brookhaven Bulletin is devoted to the Light Source, a big machine where small teams of researchers can do "small science" with big results.

In ever-increasing numbers, scientists use the Light Source's photons for research in the fields of biology, chemistry, geology, materials science, medicine, metallurgy and physics. In 1993 alone, some 2,600 users did experiments at the Light Source — making it one of the largest user facilities worldwide. The photons of the NSLS complement the neutrons of BNL's High Flux Beam Reactor; together they form a world-renowned center for scientific research.

In the basic sciences, researchers are studying the absorption and scattering of light to determine the properties of matter such as crystal structure, bonding energies of molecules, details of chemical and physical phase transformations, electronic structure and magnetic properties.

The properties of synchrotron light are well-matched to the study of surfaces. Studies of the changes in the structure and electronic properties of a crystal when going from the bulk to the surface have led to a new understanding of surfaces on the atomic level. Surfaces are also key to understanding technologically important processes such as catalysis and corrosion, and the chemical and petroleum industries use the Light Source to develop new catalysts.

The electronics industry does R&D on semiconductors, and both IBM and AT&T are developing x-ray lithography processes to produce future generations of computer chips with even smaller features than those presently produced using optical lithographic techniques.

The Light Source also serves as a training ground for future scientists, with 800 students doing research that will lead to advanced degrees and another 60 students participating in the U.S. Department of Energy's High School Honors Research Program each summer. In addition, a 1992 high school senior, Kurt Thorn, took first place in the nationwide Westinghouse Science Talent Search, based on his research at the NSLS on coastal water pollution.

"The Light Source is an invaluable resource for basic scientific and industrial research," said BNL Director Nicholas Samios. "We're tremendously proud of its contributions to increasing our national competitiveness, and we believe that the NSLS has a bright future."

Synchrotron Radiation: The Light Beyond ROY G. BIV

In 1945, the "synchrotron" was proposed as the latest accelerator for high energy physics, designed to push particles, in this case electrons, to higher energies than could a cyclotron, the particle accelerator of the day. But, before the first paper on synchrotron design was published, there was some theoretical worry about "synchrotron radiation."

An accelerator takes stationary charged particles, such as electrons, and, just as its name says, accelerates them to velocities near the speed of light. In being forced by magnets to travel around a circular storage ring, charged particles tangentially emit electromagnetic radiation and, consequently, lose energy. This emitted light is known as synchrotron radiation.

The General Electric (GE) Laboratory in Schenectady built the world's second synchrotron, and it was with this machine in 1947 that synchrotron radiation was first observed. Radiation by orbiting electrons in synchrotrons was predicted by, among others, John Blewett, then a GE physicist and now a retired BNL senior physicist.

For high-energy physicists doing experiments at an electron accelerator, synchrotron radiation causes a loss of energy. But condensed-matter physicists realized that this is exactly what they need to investigate the electrons surrounding the atomic nucleus and the position of atoms in molecules. So, in the early days, the two worked together in so-called "parasitic" operation, where synchrotron light was used to illuminate the condensed-matter physicists' experiments while particle physicists used the electron beam.

The part of the electromagnetic spectrum that the human eye can see is called visible light. In order of decreasing wavelength and increasing frequency, it is known to all schoolchildren as ROY G. BIV, for red, orange, yellow, green, blue, indigo and violet. The region with wavelengths shorter than violet is the ultraviolet and, overlapping and going beyond it, sits the x-ray region. Meanwhile, on the other side of red, with longer wavelengths, is the infrared region.

The shorter the wavelength, the higher the frequency and the more "energetic" the light. While it cannot be seen by the human eye, when used in certain ways and viewed by appropriate detectors, this light can reveal structures and features of individual atoms, molecules, crystals, cells and more, especially when the wavelength and corresponding energy of the light are matched to the size and energy of what is being viewed.

Pictured in 1977, three of the principals involved in the development of the National Synchrotron Light Source: Ken Green (left) and Renate Chasman, who designed the magnetic lattice of the two electron storage rings, and Martin Blume, then chairman of the NSLS design committee.

Because synchrotron light is very intense and well collimated, it is preferred to light produced by conventional laboratory sources.

When the U.S. Department of Energy's Office of Basic Energy Sciences recognized the need for "second-generation" electron synchrotrons dedicated to the production of light, it budgeted construction funding for Brookhaven's National Synchrotron Light Source, beginning in fiscal year 1978. Ground was broken for the NSLS on September 28, 1978, and the vacuum ultraviolet (VUV) ring began operations in late 1982, while the x-ray ring was commissioned in 1984.

Before the light at the NSLS was turned on, however, the two inspired scientists responsible for the ingenious design of the two storage rings had died. The late Renate Chasman and G. Kenneth Green had designed the "double-focusing achromat," or what is more commonly known as the Chasman-Green lattice. The lattice is the periodic arrangement of magnets that bend, focus and correct the electron beam, and their simple yet elegant design included straight sections for insertion devices.

These special magnets inserted into two and five straight sections in the VUV and x-ray ring, respectively, cause the electron beam to wiggle and, therefore, emit even more intense synchrotron radiation. Chasman and Green's inclusion of these devices in their design of the storage rings enables the NSLS to deliver world-class beams of light today.

While the NSLS is looking into the future with its research and development of a fourth-generation light source (see story on page 4), third-generation sources now coming on line owe a debt of gratitude for their design to Chasman, Green and the NSLS: the European Synchrotron Radiation Facility, which has been on line since April 1992 in France, and the Advanced Photon Source, which is now being commissioned at Argonne National Laboratory, use the Chasman-Green lattice; the Advanced Light Source, which recently began operating at Lawrence Berkeley Laboratory, uses a "triple-bend achromat" lattice designed by former BNL physicist Gaetano Vignola while he worked at the NSLS.

In serving its 2,600 annual users, the National Synchrotron Light Source is living up to its name as a U.S. resource for basic and applied research — a beacon for progress in many fields.

— Marsha Belford

At the console of the scanning transmission x-ray microscope on NSLS beam line X1A: (from left) Janos Kirz, Susan Wirick, Xiaodong Zhang and Chris Jacobsen, State University of New York at Stony Brook.

The Inside Stories

Award-Winning NSLS Technology

Just as the science at the National Synchrotron Light Source is innovative and far-reaching, so too is the state-of-the-art technology developed for use at the world-renowned facility.

Research and Development Magazine *annually issues awards for the year's top 100 technological achievements. Since 1986, technology developed for the NSLS has won six of these prestigious R&D 100 awards. Used in both basic and applied scientific studies, these inventions are listed chronologically:*

- **1986, Soft X-Ray Emission Spectrometer** — Invented by researchers from the National Bureau of Standards (now the National Institute of Science and Technology), Oak Ridge National Laboratory and the University of Tennessee, this instrument is up to 10,000 times more efficient than conventional spectrometers. At the vacuum ultraviolet ring, it is used for studying the electronic structure of solids.
- **1988, Dragon Monochromator** — AT&T Bell Laboratories researchers invented this high-resolution, soft x-ray monochromator to isolate particular wavelengths of soft x-rays for core-level photoabsorption studies on the electronic structure of many diverse materials. With its record-breaking, energy-resolving power, this monochromator design has been copied worldwide.
- **1988, X-Ray Microscope/Microprobe** — Researchers from BNL and the University of Chicago invented this novel instrument for determining the chemical composition of geological and biological samples. To examine the concentration and spatial distributions of trace elements in materials, it uses a technique called x-ray fluorescence. The device provides up to a thousandfold greater sensitivity than competing instruments, while causing less damage to the sample.
- **1989, Real-Time Closed-Orbit Correction System** — BNL researchers developed this system to stabilize the orbit of the electron beam at the NSLS. This is the only system of its kind that can correct the beam's fluctuations over the whole storage ring in real time. For most beam lines, beam stability has been improved by more than a factor of 10. The short-term movement is reduced to a few microns, significantly enhancing experimental results.
- **1990, Wavefront Dividing Infrared Interferometer** — Developed by a BNL/Fairleigh Dickinson University/Yale University collaboration, this device splits synchrotron light into two beams, with one beam passing through the sample. When the beams are recombined, an interfer-

(continued on page 4)

Light Line

1947 — Synchrotron radiation first observed experimentally.

1973 — Design of Chasman-Green Lattice completed.

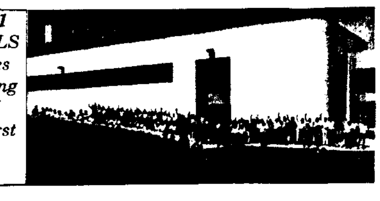
1975-77 — Martin Blume heads BNL committee to design and develop NSLS.

1977 — President Ford's budget includes $24 million for NSLS construction.

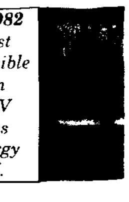
September 28, 1978 — NSLS ground breaking; NSLS Project Head Ari van Steenbergen and DOE's Donald Stevens dig in.

May 21-22, 1979 — First NSLS Users Group formed with 75 prospective members; PRT concept approved.

Aug. 12, 1981 — (right) NSLS staff celebrates first circulating beam in VUV ring; beam first stored in December.



May 20, 1982 — After first beam of visible light is seen (right), VUV ring reaches design energy of 700 MeV.



A Sampler of Current I

Light Byte: Around the Rings

The National Synchrotron Light Source produces synchrotron radiation for researchers to use in a variety of experiments. In fiscal year 1993, some 1,100 experiments were performed on the 85 beam lines of the NSLS' two storage rings. Highlighted on these pages are six experiments — four from the x-ray ring and two from the vacuum ultraviolet (VUV) ring — a representative but far-from-comprehensive sampling of current research and researchers at the Light Source.

At beam lines X10B and X10C are Exxon researchers Brian DeVries (front) and Michael Sansone.

X10C — Catalyst Studies

Modern refining technology depends on catalysts to convert raw materials into useful products, such as low-octane hydrocarbons into motor gasoline. Even small improvements in a catalyst's efficiency can lead to large savings in production.

Among the research conducted at Exxon's beam line X10C are investigations of catalysts at the atomic level, using a technique called x-ray absorption spectroscopy to determine the geometric and electronic structure of catalysts. In this method, researchers measure the fraction of photons absorbed by the sample as the energy of the x-ray changes. Solid, liquid or gaseous samples can be studied by this technique.

"We can study different elements in a complex structure," said Exxon researcher Grayson Via. "We can also bring reactive gases into the experimental area and examine the state of the catalyst as it actually functions."

Recently, Grayson and his associates have examined catalysts that contain tiny bimetallic clusters, no more than two nanometers each. By changing the surface composition of these catalysts, the researchers can alter the mix of chemical products they produce by changing the rates at which they are made.

Explained Grayson, "By changing the composition of a catalyst, we can get more of a desired product. For example, we might manufacture gasoline more economically or change its composition so that its use would be safer for the environment." — D.G.

Light Byte: X-Ray Ring

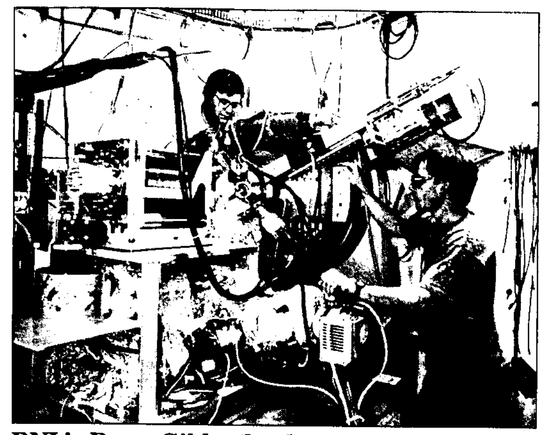
Photons from the x-ray ring are used to determine the atomic structure of materials using diffraction, absorption and imaging techniques. Many of the crystal structures of new materials such as high-temperature superconductors and Buckminsterfullerenes have been determined from data taken at the NSLS. The surface crystal structures of many different metals and semiconductors were elucidated, and phase transformations as a function of temperature studied. Structures of biological importance and of potential new drugs are being solved.

X-ray absorption studies are leading to a new understanding of catalysis and to the development of industrially important new catalysts. BNL scientists are studying corrosion and electrochemistry.

A number of x-ray imaging techniques have been developed, including soft x-ray microscopy to study live cells, computed x-ray microtomography to study porous media and a new, less-invasive method of coronary angiography.

X-ray ring facts include:

Circumference — 170 meters
Energy — 2.5 billion electron volts
Current — 250 milliamperes
Average beam lifetime — 20 hours
Beam ports — 30
Beam lines — 60
Insertion devices — 5
Operations — 5,200 hours/year
Reliability — 96 percent



BNL's Doon Gibbs (back) and Gavin Watson do x-ray diffraction on beam line X22.

X22 —

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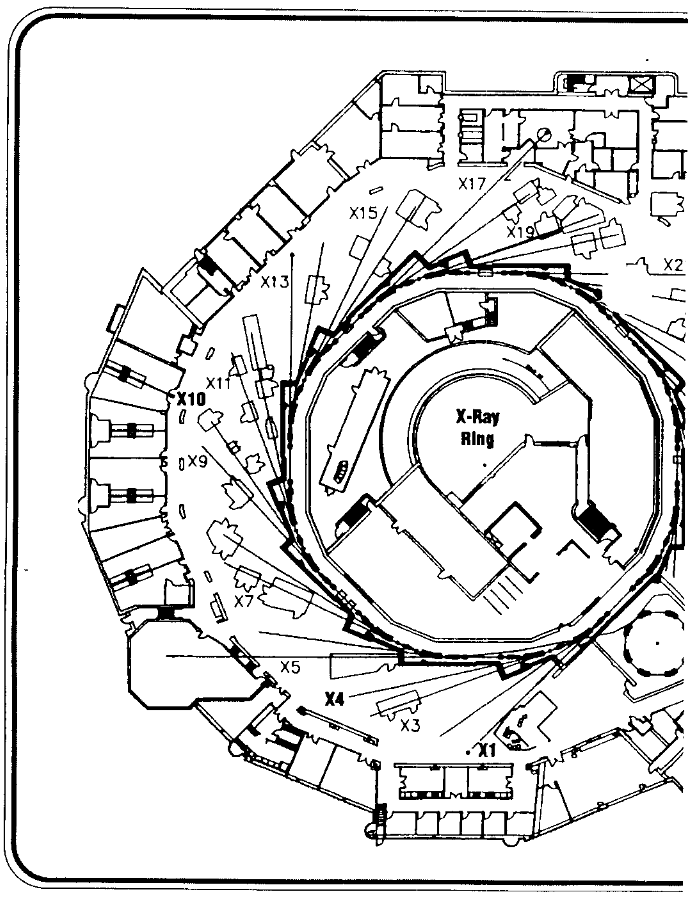
In x-ray diffraction, the x-rays generated by the NSLS are used to de
The x-rays scattered from the atoms interfere to produce a diffractio
intensity can be unscrambled to give the geometrical arrangement



X4 — MAD Crystallography

Synchrotron radiation has allowed the three-dimensional structural analysis of protein crystals to be performed with much greater precision, using conventional methods of multiple isomorphous replacement (MIR) and molecular replacement. Now, experiments at NSLS beam line X4 are proving that another method — called multiwavelength anomalous diffraction (MAD)— can just as easily be used to reveal the structures of heretofore unsolved proteins. Moreover, the MAD method makes it feasible to solve some otherwise intractable problems in structural biology.

Structurally, a crystal is a three-dimensional, periodic arrangement of atoms in space, and it happens that a crystal acts as a diffraction grating for x-rays. While the structures of small molecules have been relatively easy to solve because of the small number of atoms that have to be located, larger molecules such as proteins required MIR techniques.

Inside the hutch at beam line X4 are Howard Hughes Medical Institute researchers: (from left) Craig Ogata, Walter Zotterman, Randy Abramowitz, Xiaochun Yang and David Cook.

With MIR, diffraction data are gathered on the protein crystal under study and on at least one isomorphous crystal — one that has a similar crystalline structure into which a heavy atom such as mercury or platinum has been introduced.

Since not all proteins have isomorphous cousins of identical structure, "MAD was developed to take advantage of the physics of scattering rather than the chemistry of isomorphous replacements," explained Howard Hughes Medical Institute investigator and Columbia University professor Wayne Hendrickson, who, with his collaborators, carries out MAD development and research on NSLS beam line X4.

After replacing only one atom within the protein with a heavy atom, the crystal is studied using multiple wavelengths of synchrotron radiation. The wavelengths used are above, below and equal to the binding energy for an electron in one of the shells closest to the heavy atom's nucleus because the scattering power is wavelength-dependent in this region.

Most recently, the structure of human chorionic gonadotropin, a hormone needed to sustain pregnancy, was solved using MAD. Since form often not only follows function, but also determines how proteins work, solving structures of important proteins will add to the understanding of their biological functioning. — M.B.

Light Byte: PRTs

An innovative concept initiated with the Light Source is the idea of Participating Research Teams, or PRTs. Each PRT agrees to build a state-of-the-art beam line and guarantees that the beam line will be available 25 percent of the time for peer-reviewed general user proposals. The PRT then has the remaining 75 percent to do its own research. The PRT's tenure is reviewed every three years by the NSLS Science Advisory Committee. Over the years, PRTs have invested over $125 million in capital and about 1,200 person years of labor to design and install their own experimental equipment.

Most of the research performed at the NSLS is published in the scientific literature, and there is no charge for beam time. However, both PRTs and general users can do proprietary work, in which case they pay full-cost recovery for beam time.

This arrangement is particularly appealing to industrial users, because they can keep title to any inventions and treat as proprietary all data generated during work at the Light Source.

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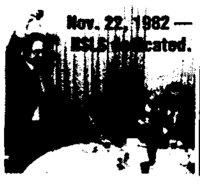
Sept. 3, 1982 — First beam storage achieved in x-ray ring.



1982 — First soft x-ray scanning microscope commissioned on beam line U15; provides images of biological specimens like this diatom.

Dec. 16, 1983 — (left) NSLS staff gathers in control room to see first x-rays come down beam line.

Feb. 14, 1985 — First EXAFS spectrum taken at x-ray beam line X11

May 1985 — (right) First diffraction pattern from a macromolecule recorded on film at crystallography beam line X13B.

Aug. 19, 1985 — X-ray ring reaches design energy of 2.5 GeV.

Sept. 1986 — First R&D 100 award won for NSLS success; NSLS Phase II upgrade shutdown begins.

1986 — First x-ray surface scattering experiment performed, an Si(111) 7x7 reconstruction on beam line X16A.

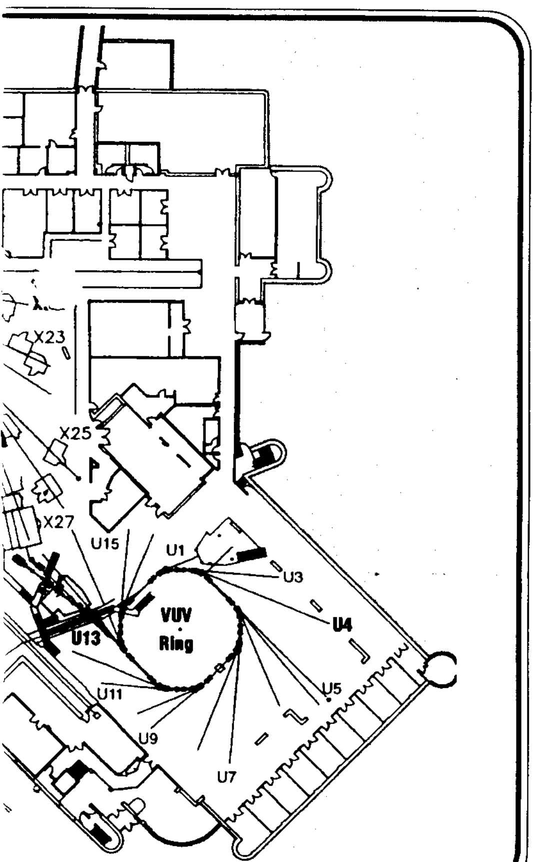
May 29, 1987 —First gamma rays seen at LEGS, world's only Laser Electron Gamma Source.

:xperiments at the National Synchrotron Light Source

X-Ray Diffraction

ıs to a surface of a material when a sample is heated ing temperature, or in response to an applied voltage? · kinds of questions being answered on beam line X22, sicists and their collaborators use x-ray diffraction to ıgement of atoms on the surface of materials and how ıd· 'ferent conditions.
ırop ›s of materials are important to the computer, poly. .er and coating industries. Thus, the scientists stals, which have some of the properties of both solid ·s, to see how they are organized near the surface of a – useful information for making the displays of digital alculators and thermometers.
one discovery showed that a type of gold surface, ıt a temperature lower than the atoms in the interior, e at the surface.
nother experiment showed that, in liquid waxes, the ve the problem of diesel-fuel crystallization in cold

termine the positions of atoms in the sample material. pattern. The resulting distribution of scattered x-ray ıf all the atoms in the sample. — L.S.



Light Byte: VUV Ring

Experiments at the vacuum ultraviolet (VUV) ring help elucidate the atomic and electronic structure as well as the magnetic properties of a wide array of materials.

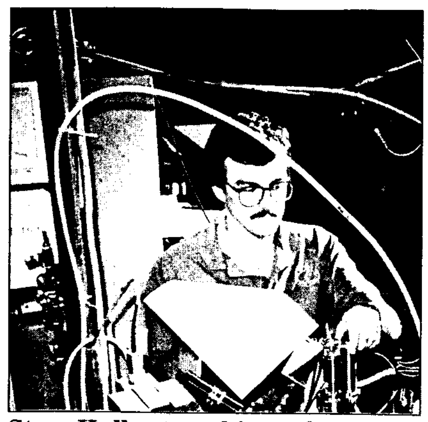
Using the technique of high-resolution angle-resolved photoemission, physicists map out so-called Fermi surfaces; with spin-polarized photoemission and magnetic circular dichroism, they study the magnetic properties of thin films and multilayers. Photoemission and infrared studies may help researchers explain high-temperature superconductivity. To understand chemical reactions, chemists investigate molecules in the excited state. To work toward developing a vaccine, BNL biologists use circular dichroism and fluorescence to understand how antibodies interact with the surface protein of Lyme disease.

The most notable achievement of VUV ring research is the development of soft x-ray lithography by IBM and AT&T for the manufacturing of the next generation of high-density computer chips.

VUV ring facts include:
Circumference — 51.0 m
Energy — 750 million electron volts
Current — 950 milliamperes
Avg. beam lifetime — 4 hr.
Beam ports — 17
Beam lines — 25
Operations — 6,000 hr./yr.
Insertion devices — 2
Reliability — 98 percent

U13U — Chemical Dynamics

Since 1991, the U13UA beam line has been delivering an intense and high-resolution beam of soft x-ray photons — in the 100-1,000 electron-volt energy range — for fundamental research in a wide variety of chemistry and solid state physics experiments.



Steve Hulbert working at beam line U13U.

The source of the photons is the U13 wiggler, some 50 times brighter than a VUV bending magnet, and delivering ten times more photons onto the sample.

In one collaboration, scientists from the State University of New York (SUNY) at Stony Brook and BNL study the chemical dynamics of the innermost core electrons of small molecules. Said David Hanson, the SUNY research team leader, "We are particularly interested in molecules containing carbon and oxygen, which are common to many organisms." One experiment looked at the spectrum of electrons emitted from the innermost core levels of carbon and oxygen in acetone irradiated with soft x-ray photons. The decay products gave information on the acetone's electronic structure — allowing researchers, for example, to distinguish between different carbon atoms in the molecule.

"We also study photo-fragmentation — the ionic products created when molecules fly apart in reaction to a photon beam," said Hanson. Using two detectors set 90 degrees apart, the team has measured the angles at which specific ion species are emitted and determined the nature of excited states of nitrogen and water molecules following excitation of their innermost core electrons. — L.S.

U4B — Magnetism Studies

Computers, tape recorders, and specialized recorders for storing data in research, industrial and military applications all depend on magnetic thin films to function.

At beam line U4B, AT&T Bell Laboratories researchers are using "soft" x-rays with the Dragon monochromator (see page 1) for a technique called magnetic circular dichroism (MCD), to study magnetism in a wide range of systems, including thin films, alloys, surfaces, ferrites and proteins.

AT&T Bell Laboratories researchers Varoujan Chakarian (top) and Jaehoon Park, at beam line U4B.

MCD is the difference in the absorption of light by magnetic systems using circularly polarized light, in which an electric field rotates in either a left or right-handed manner. On an atomic scale, a material's magnetism is attributed to its magnetic moment — the sum total of all its electrons' orbital motions and spins. MCD can determine, with element and site specificities, the electron orbital and spin contribution to the magnetic moment of transition metals and rare earths.

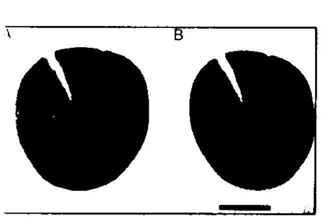
AT&T physicist C.T. Chen said, "We made the first MCD measurement using soft x-rays in 1989. Recently, working with researchers from BNL and the Naval Research Laboratory, using both MCD and x-ray reflectivity measurements, we discovered novel coupling in certain thin-film multilayers, such as iron-nickel-silver and iron-cobalt-magnesium. This information is important for improving recording heads so that they are as sensitive as possible."

This magnetic coupling refers to how the magnetic layers line up — either ferromagnetically, in which all the magnetic moments of each layer face in the same direction, or antiferromagnetically, in which the magnetic moments face opposite directions. — D.G.

X1A — Soft X-Ray Imaging

In 1982, the world's first scanning x-ray microscope to achieve resolution beyond the limit of the optical microscope was built at the NSLS, by Janos Kirz and his collaborators from the State University of New York at Stony Brook and from IBM. First located on the VUV ring, the microscope was moved to beam line X1A in 1989, when scientists from Lawrence Berkeley Laboratory and the NSLS Department joined the team. At X1A, its speed and resolution have been improved due to the very bright soft x-rays provided by an insertion device called an undulator and new focusing optics.

While the scanning soft x-ray microscope cannot match the resolution of the electron microscope, it has several advantages that are being capitalized upon in research. For instance, not only can thicker specimens be viewed, wet or dry, at atmospheric pressure, but also a series of images of one dry specimen can be taken because the radiation exposure causes relatively little damage. This has been useful in studying the blood stage of malaria, which is being done by BNL's Biology Department in a search for a new vaccine, and in mapping the distribution of protein and DNA in sperm, which is being performed by Lawrence Livermore National Laboratory to understand male infertility better.



Images of the same Kevlar fiber, provided by Harold Ade, North Carolina State University, reveal the radial symmetric structure of specific chemical groups when viewed on beam line X1A — with x-ray linear di· ·ism microscopy.

In addition, the x-ray microscope can identify chemicals in a sample and the direction of specific chemical bonds — important, for example, in the study of Kevlar, a material used in many applications, including bulletproof vests. To improve the fiber, scientists from North Carolina State University and DuPont are interested in correlating the chemical structure of various grades of Kevlar with its physical properties.

"X-ray microscopes are not meant to replace electron or even optical microscopes, but to contribute complementary information not otherwise obtainable," explained Janos Kirz. "As synchrotron technology improves, so too will the capabilities of the soft x-ray microscope, and this promises new insights in biology, chemistry, medicine and solid-state physics." —M.B.

Light Byte: User Profile

The NSLS is used by more than 2,600 researchers annually, with some 450 conducting experiments at the VUV ring and 2,150 at the x-ray ring. Light Source users represent a variety of scientific disciplines and include chemists, biologists, geologists, materials scientists, metallurgists and physicists.

Hailing from about 46 different countries, these users include:

Area	PRT beam lines	Users	Institutions
U.S. Industry	24	345	66
U.S. Academia	16	1,343	155
U.S. Govt. Labs	15	358	28
BNL	30	136	1
U.S. Other	0	63	12
Foreign Users	0	397	156

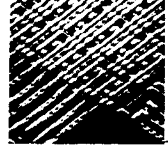
Nov. 18, 1987 — First infrared spectrum taken at U4IR, 1,000X brighter than conventional infrared sources.

***1988** — X-ray microtomography developed at NSLS beam line X10A, making possible three-dimensional images showing 1000 times more detail than ever seen before, as in the cross-section of a piece of coal at left.*

1988 — Dragon monochromator achieves resolving power of 10,000 at 400 electron volts.

Feb. 1988 — VUV ring reaches current of 1.5 amperes.

July 10, 1988 — First light seen from first Phase II insertion device, an undulator.



July 1988 — IBM uses the VUV ring's soft x-rays to produce densely packed computer chips, the first ever made solely using x-ray lithography.

1989 — Research starts on magnetism using magnetic circular dichroism and resonant scattering at $L_{II}L_{III}$(Ni) and M_{IV}(U) edges.

1989 — First demonstration of global-orbit feedback on VUV ring.

Mar. 16, 1989 — Light emanates from new superconducting wiggler.

nsls uv x

Research Transfer From Beam Line to Assembly Line, and Beyond

No one doubts the importance of basic research, but today there is also recognition of the urgent need to turn fundamental discoveries into practical applications. Nowhere is enthusiasm for this greater than at the National Synchrotron Light Source, where about 350 industrial scientists from about 70 companies are pursuing research that may lead to future innovative technologies.

The most striking example of this technology transfer from BNL's Light Source to the outside world came in July 1988, when IBM announced that it had used x-ray lithography at the NSLS' vacuum ultraviolet ring to make the most densely packed working computer chips in the world. With only 0.5-micron spaces between components, the test chips were approximately two times denser than any mass-produced chip of the time.

"Based on our success at the NSLS," said IBM's Jerry Silverman, "we have built our own synchrotron storage ring in East Fishkill, New York, where we now consistently make chips with features as small as 0.25 microns. We're working to make this technology production-worthy." As the technology progresses, the number of circuits on chips are expected to increase about one hundredfold, making computers faster and more efficient.

In the same pursuit, AT&T Bell Laboratories is developing a type of lithography at the NSLS called extreme ultraviolet projection lithography, which uses longer wavelengths than IBM's shadow mask x-ray lithography. In the AT&T method, which is far from the production stage, features as small as 0.05 microns have been imaged.

The NSLS is also at the forefront of developing medical technologies. For example, researchers from BNL, working with collaborators from Stanford University, the State University of New York at Stony Brook and North Shore University Hospital, use NSLS x-rays for transvenous coronary angiography, a technique that produces research-quality images of human coronary arteries. Since this angiography procedure requires catheterizing a vein, rather than a plaque-clogged coronary artery, risk to the patient is reduced.

BNL scientists are currently working with two industrial partners — Advanced Acoustic Concepts Inc. and Science Research Laboratory, Inc. — to improve the image-display system for this alternative angiography and to produce a compact source of x-rays for hospitals and clinics.

In a different sort of medical research, numerous pharmaceutical company researchers are working on rational drug design at the NSLS Structural Biology Center. This approach to creating new drugs can often involve designing inhibitors, molecules that attach to enzymes and stop the action of disease-causing agents. These projects range from an investigation by Sterling Winthrop, Inc., and Purdue University into the rhinovirus that causes the common cold, to SmithKline Beecham Pharmaceutical and Monsanto's studying the HIV protease associated with AIDS.

Other teams at the NSLS are working on remedies for environmental problems. In one case, scientists from the Savannah River Ecology Laboratory and the University of Chicago, along with BNL researchers, are using a technique called x-ray absorption spectroscopy to study the specific oxidation states of toxic metals and radioisotopes in contaminated soils at U.S. Department of Energy nuclear-processing facilities. Using an x-ray microprobe to determine how the oxidation varies within the sample, the scientists collect data on the extent of toxicity in the soil and the behavior of the atoms in it.

A technique called x-ray computed microtomography, similar to CAT scanning but able to resolve features 1,000 times smaller, is used by researchers from BNL, Amoco, Exxon, IBM and Mobil to look at the inner structure of opaque, heterogeneous materials with micron resolution.

As John Dunsmuir of Exxon explained, "We can look at the pore structure of oil reservoir rocks in three-dimensional images, map out the pore space and integrate these data with our models. Such information may allow us to manage oil reserves more carefully, increase oil production, or perhaps extract oil using methods that are better for the environment."

— Diane Greenberg

The Future of The Brightest

Anticipating the future needs of its users, the National Synchrotron Light Source Department continually upgrades the facility. "In the minds of our users, the NSLS has been synonymous with state-of-the-art," said Denis McWhan, NSLS Department Chairman, "so, we're carrying out great plans to maintain that reputation for many years to come."

UP With the UV Free Electron Laser

Over five years ago, NSLS researchers began to look for ways to develop a source of radiation in the vacuum ultraviolet (VUV) energy range, to bridge the gap between what can be provided by conventional laser technology and synchrotron radiation sources.

Building on the achievements of the Accelerator Test Facility (ATF) in BNL's Center for Accelerator Physics, Brookhaven stands poised to embark on an ambitious series of experiments to develop a short-wavelength free-electron laser (FEL) operating in the VUV. This work will ultimately lead to the development of an FEL-based facility serving users in fields as diverse as photobiology, materials science, and chemical, surface and solid-state physics.

BNL researchers have made important contributions to FEL-related science and technology. High-brightness photo-injectors and other key FEL components have been developed at the ATF, which is headed by NSLS physicist Ilan Ben-Zvi. Together with Ben-Zvi, NSLS physicists Li-Hua Yu and Sam Krinsky proposed an experiment to demonstrate high-gain harmonic generation in FELs, now being conducted at the ATF. These cornerstone developments are all important elements of the new experiments at BNL known collectively as the Ultraviolet Project [UP].

A broad-based collaboration of several national laboratories, universities and industrial partners, UP seeks to develop the technology needed for high peak power, single-pass FELs operating in the VUV. The UP-FEL is being built around two major systems: a linear accelerator originally built for the superconducting x-ray lithography source at BNL, and a 10-meter-long permanent magnet undulator built for an infrared FEL at Boeing. This will be moved to BNL from Seattle this summer. "Such recovered resources," said Erik Johnson, NSLS, who oversees the project, "save nearly $15 million."

One important aspect of the project is the concurrent development of the accelerator technology along with user experiments. In many ways, the UP-FEL will be orders of magnitude above existing sources: Peak power will be one gigawatt; wavelengths will range from 300 down to 120 nanometers (nm), bandwidth tunability will be 0.01 to 4 percent, and short duration pulses will be measured in femtoseconds — sufficiently short and intense to allow "snapshots" of chemical reactions to be taken, even as they occur.

As NSLS Chairman Denis McWhan explained, the UP-FEL experiments will be a valuable first step to a proposed user facility dubbed the Deep Ultraviolet Free Electron Laser (DUV-FEL). At an estimated cost of $35 million, the DUV-FEL is a longer-term prospect than the UP-FEL, but its promise will be worth the wait: The DUV-FEL will extend the wavelength range down to 75 nm, increase the pulse repetition rate, and provide four experimental beam lines and experimental support facilities.

— Liz Seubert

BROOKHAVEN BULLETIN

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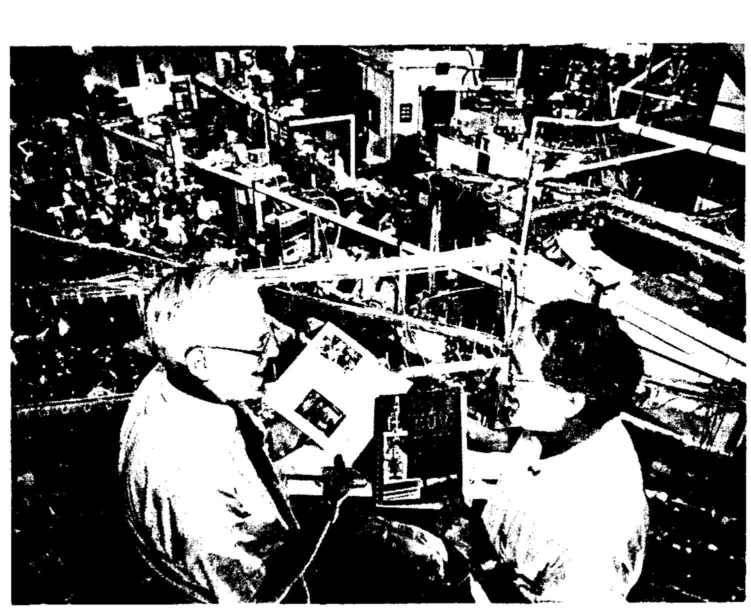
New Heights of Performance

To provide NSLS users with a reliable, stable and bright photon beam, a program of upgrading and modification is raising the accelerator's systems to new performance heights.

Said NSLS Deputy Chairman Samuel Krinsky, "Our aim is to suit the experimental needs of all NSLS users with the best performance and greatest versatility possible, providing our users with an environment where great science can be done."



Denis McWhan (left) and Samuel Krinsky survey the busy floor of the NSLS vacuum ultraviolet ring.

Key to improving reliability, explained Krinsky, has been the upgrades of the computer control and beam-injection systems. A formidable hurdle to upgrading the computer control system was the question of how to replace the hardware without disrupting operations. Last year the department's computer group solved the problem by allowing control of the old and the new systems simultaneously. The successful upgrade has made it possible to carry out state-of-the-art application programs, real-time diagnostics and error monitoring and alarms.

The upgrade of the beam-injector, which supplies electrons to the two storage rings, has involved installing new power supplies for the booster magnets, new modulators for the radio frequency (rf) of the linac and new electron-beam diagnostics.

"As a result of these improvements," Krinsky said, "we expect to be able to double the charge rate of the storage rings — so users will lose less time between fills."

Over the last few years, orbit stability has been dramatically improved. New rf receivers, which process signals from the pickup electrodes that monitor the beam's orbiting position in the x-ray and vacuum ulltraviolet (VUV) storage rings, have been installed and provide high-precision, real-time data. Newly designed feedback systems, which send signals to the correction magnets, now stabilize the orbit globally for the entire ring.

Upgrade of the x-ray ring rf system has made it possible to double the current. The NSLS already shines brightly as a source of synchrotron radiation, but, said Krinsky, by doubling the operating current and reducing the vertical beam size, the Light Source will be ten times brighter one year from now.

Longer term R&D is also proceeding, including two innovative insertion devices to be tested in the x-ray ring — a small-gap undulator and, in collaboration with Argonne National Laboratory scientists, an elliptically polarized wiggler. On the VUV ring, the operation of a fourth harmonic cavity is being optimized. This cavity increases the length of the electron bunches, which reduces the rate of beam loss due to the scattering of electrons off each other. A further possible improvement under consideration is increasing the operating energy of the VUV ring.

— Liz Seubert

R&D 100 Awards

(continued from page 1)

ence pattern results, providing data on the sample's electronic structure. With a signal-to-noise ratio 1,000 times better than conventional instruments, this device can measure highly absorbing samples, such as high-temperature superconductors, and dilute systems, useful for catalysis and corrosion studies.

• **1991, Scanning Photoemission Microscope** — This x-ray microscope was developed by a collaboration of scientists from the NSLS, IBM, Lawrence Berkeley Laboratory and the State University of New York at Stony Brook to study the elemental and chemical composition of surfaces, as well as their electronic structure. It is the first photoemission microscope with submicron resolution and elemental sensitivity.

— Diane Greenberg

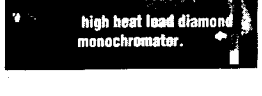
Light Line (cont.)

Aug. 1990 — First nuclear forward scattering from ^{57}Fe observed.

1990 — First observation of reconstruction of an Au(001) surface in an electrochemical cell, at beam line X22.

***Oct. 5, 1990** — Human-heart images are first made at the x-ray ring using transvenous angiography.*

***Mar. 9, 1992** — Kurt Thorn wins Westinghouse Science Talent Search for his NSLS research.*



1992 — Development of isotopically enriched high heat load diamond monochromator.

1993 — At the x-ray ring, current reaches 500 milliamperes and brightness is increased ten times.

Apr. 4, 1994 — Construction begins on Structural Biology addition to NSLS.

1994 — New x-ray ring techniques produce mechanical components several centimeters in size, but with precision of micromachines.