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Annual Meeting of the Advanced Light Source Users' Association

October 21-22, 1993

Lawrence Berkeley Laboratory

Organized By

ALS Users' Executive Committee

March 1994

MASTER

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Preface

The opportunity to see the first experimental results from ALS beamlines attracted a record number of persons to the Advanced Light Source Users' Association Annual Meeting held at Lawrence Berkeley Laboratory (LBL) on October 21 and 22, 1993. For most of the 220 attendees, this was the first chance to see the ALS in operation and view the initial set of beamlines on the experimental floor. The meeting program focused on the scientific opportunities offered by the ALS' ability to produce the world's brightest beams of ultraviolet and soft x-ray synchrotron radiation. A special highlight was the chance to participate in the ALS Dedication Ceremony held on October 22.

The program was organized by the chair of the ALS Users' Executive Committee, Dave Ederer (Tulane University), and began with a welcome by LBL Director Charles V. Shank. Shank encouraged everyone to join LBL in the challenge of creating a world-class scientific program at the ALS that would fully exploit its capabilities.

Following Shank's remarks, ALS Director Brian M. Kincaid gave an account of the facility's progress during the past year and outlined plans for the first year of operations. After a highly successful accelerator commissioning run in the spring, the ALS focused its efforts on installing the beamlines and instrumentation for the first phase of operations. Kincaid reported that three of the initial set of five beamlines were already operational: the x-ray microprobe bending-magnet beamline, an undulator beamline, and the diagnostic beamline. He concluded by thanking everyone involved for their contributions to the remarkable success of the ALS.

Dave Shirley (Pennsylvania State University), who was LBL's director when the ALS was conceived, noted with satisfaction that the completion of the facility brought the scientific community to the threshold of a dramatic new opportunity. He emphasized the importance of developing experimental apparatus, particularly high-performance detectors, that can take full advantage of the qualities of the ALS light.

William Oosterhuis of the Office of Basic Energy Services at the U.S. Department of Energy provided an overview of the funding climate for experimental facilities and for research at synchrotron-radiation facilities.

Neville Smith (AT&T Bell Laboratories) discussed his role as head of the ALS Program Review Panel. The Panel, whose membership provides a balanced representation of the major scientific and engineering disciplines covered by the ALS, gives advice on the disposition of proposals for the development and use of ALS experimental facilities. To illustrate how the committee works, Smith described the process by which the panel evaluated the initial beamline proposals.

The last speaker of the morning was Glen Dahlbacka from LBL's Technology Transfer Department who spoke about industrial opportunities at the ALS. He discussed two proposals currently under consideration of interest to industry: an x-ray crystallography beamline and a microfabrication facility. The crystallography beamline would form the heart of a user facility for protein study to assist industry in the areas of rational pharmaceutical design and development of new commercial catalysts. The proposed microfabrication facility would use deep x-ray lithography for the production of micromachines such as precision gears for watches, accelerometers for use in automobile airbags, and miniature instruments for microsurgery.

Howard Padmore, ALS Experimental Systems Group Leader, talked about the first experimental results from the operational beamlines along with plans for future beamlines. He showed an image of the beam taken from the CCD detector at the end of the diagnostic beamline and a spectrum obtained with the transmission grating spectrometer being used to measure the light from the recently operational 5-cm-period undulator. Padmore discussed initial plans for an 8-cm-period undulator branchline for chemical dynamics studies and a crystallography beamline for industrial users.

Fred Schlachter, ALS User Liaison Group Leader, described the efforts of the ALS to develop new research opportunities and to provide an efficient working environment for users. To complete the overview of user issues, Georgeanna Perdue, acting ALS EH&S Program Manager, gave a short talk describing her role in making the ALS a safety-conscious facility and outlining the training requirements for ALS users.

Richard White (University of California at Berkeley) spoke on the research being done by the Berkeley Sensor and Actuator Center (BSAC) to develop a science and engineering base for microsensors, microactuators, mechanical microstructures, and microdynamic systems. White pointed out that the ability to make much thicker micromachines by using the light of the ALS offers many advantages such as an increase in volume which provides more mass and strength, and the possibility of using alternative materials and fabrication methods, e.g., cast polymers for non-planar shapes.

Albert Thompson (LBL Center for X-Ray Optics) finished the day's program with an exciting report about the results from the x-ray fluorescence microprobe, the first beamline at the ALS. Thompson pointed out a few of the many advantages of the microprobe, such as small spot size (1 µm by 1 µm) and femtogram elemental sensitivity. The talk included several examples of how the microprobe will be used for research in materials sciences. Among these were investigating how trace elements are distributed in ceramics, mapping the composition of fluid inclusions in quartz samples for geological studies, and elemental analysis of ancient documents.

That evening, the conference banquet featured a special talk by Albert V. Baez on the early days of x-ray optics. In 1948, Kirkpatrick and Baez devised an imaging system to eliminate the astigmatism of a single mirror used at glancing incidence. The mirror scheme turned out to be very useful in many x-ray optics applications. In fact, many modern beamlines including the microprobe and diagnostic ALS beamlines employ configurations that are similar to the Kirkpatrick-Baez scheme.

The second day began with a session devoted to spectroscopy in the soft x-ray spectral region served by the ALS. Gerhard Materlik (HASYLAB) described experiments using x-ray standing waves in the soft x-ray region. In the experiments, one can map the locations of surface species from the probe response as the positions of the standing-wave maxima and minima are varied. Materlik noted several advantages of using soft x rays, including accessibility of atoms with low atomic numbers and the possibility of using several probes in addition to the conventional fluorescence.

Günter Kaindl (Freie Universität Berlin) presented an overview of high-resolution spectroscopy experiments using the SX-700 II plane-grating monochromator, which has demonstrated a resolving power of up to 16,000 at a photon energy of 65 eV. Joseph Nordgren (Uppsala University) ended the morning session with a discussion of soft x-ray emission spectroscopy. In providing information about unfilled states, soft x-ray emission provides information complementary to that from photoabsorption and photoemission.

The morning session ended early so that the attendees could join LBL employees and guests at the ALS Dedication Ceremony outside the ALS building. Key speakers at the festive event included Charles V. Shank, director of LBL; David Shirley, senior vice president for research and dean of the graduate school at Penn State; Gayle Wilson, wife of California Governor Pete Wilson; Martha Krebs, associate director of LBL; Hermann Grunder, director of the Continuous Electron Beam Accelerator Facility; Donald Pearman, Jr., manager of DOE's San Francisco Operations Office, and Brian M. Kincaid, ALS director.

The conference resumed as Paolo Carra (ESRF) began the afternoon talks with a discussion of the theoretical aspects of magnetic circular dichroism (MCD) and linear dichroism. Steven Cramer (University of California at Davis) described biological applications of soft x-ray and MCD spectroscopy. He noted the elliptical wiggler being designed and constructed by the ALS could increase by a few orders of magnitude the flux of polarized light relative to that from bend magnet beamlines.

The final speaker, Yuan T. Lee (University of California at Berkeley), discussed plans for a chemical dynamics 8-cm-period undulator branchline for research on primary photodissociation and photoionization processes. The branchline has two primary end stations, one using white undulator light and the other using monochromatized radiation. The experimental end stations will be a complex system using pump-and-probe techniques with high power lasers and crossed molecular beams. Lee described the project as a national user facility for the study of fundamental chemical processes— especially combustion, radicals, and excited states.

Dave Ederer, chair of the Users' Executive Committee, ended the meeting by thanking everyone for their participation and encouraging the users to take an active role in creating an exciting and innovative scientific program at the ALS.

Welcome to the Annual Meeting of the ALS Users' Association

Charles S. Shank

Director
Lawrence Berkeley Laboratory
Berkeley, CA 94720

I am delighted to be here, and would like to welcome you to Lawrence Berkeley Laboratory and the Annual Meeting of the Advanced Light Source (ALS) Users' Association. Today is a day I think will be of great historical importance for LBL. It marks the beginning of our celebration of a great success; a success for the Laboratory, a success for the Department of Energy, and a success for our partnership.

We take great pleasure in the fact that the ALS project was completed on time and within budget. And to me, this is just the beginning. We now face the challenge of creating a great scientific program to match the unique capabilities of the ALS, while realizing this depends on our making it a first-rate user facility. That is why I ask you, representatives of the user community, to help us to improve the way we run and operate the ALS. It is new for us, and we value your suggestions.

I believe the secret to making this the grand success that it will be is to leverage on what we have done in the creation, construction, and operation of this project. To go on and make this, in addition to a machine that runs, one that delivers world-class science.

There are many people in the audience that we will be recognizing at the ALS Dedication tomorrow for their marvelous contributions to this project; from their insight in the beginning to build the machine, through its construction, and to bring it to where it is today. I'm going to wait until tomorrow's ceremony to go into that in a great deal of detail, but I want to congratulate all of you for making this a great day for science at LBL.

Overview of the ALS

Brian M. Kincaid

Director, Advanced Light Source
Lawrence Berkeley Laboratory
Berkeley, California 94720

My presentation will give a brief summary of the ALS' progress during the past year, with particular attention to the remarkable accomplishments of the past few months.

I will start by reminding everyone why we built the ALS. The ALS was designed to move the evolution of synchrotron radiation forward. Earlier-generation machines started with bending magnets, which produce a broadband spectrum. These were circular machines, as shown on the left in Figure 1. Third-generation synchrotrons like the ALS are designed to have several long, straight sections for insertion devices such as undulators, making them more like the polygon-shaped structure. The radiation spectrum that comes from an undulator, rather than being a broadband spectrum, is a tunable, partially coherent spectral peak. Producing this kind of light is the major purpose of the ALS.

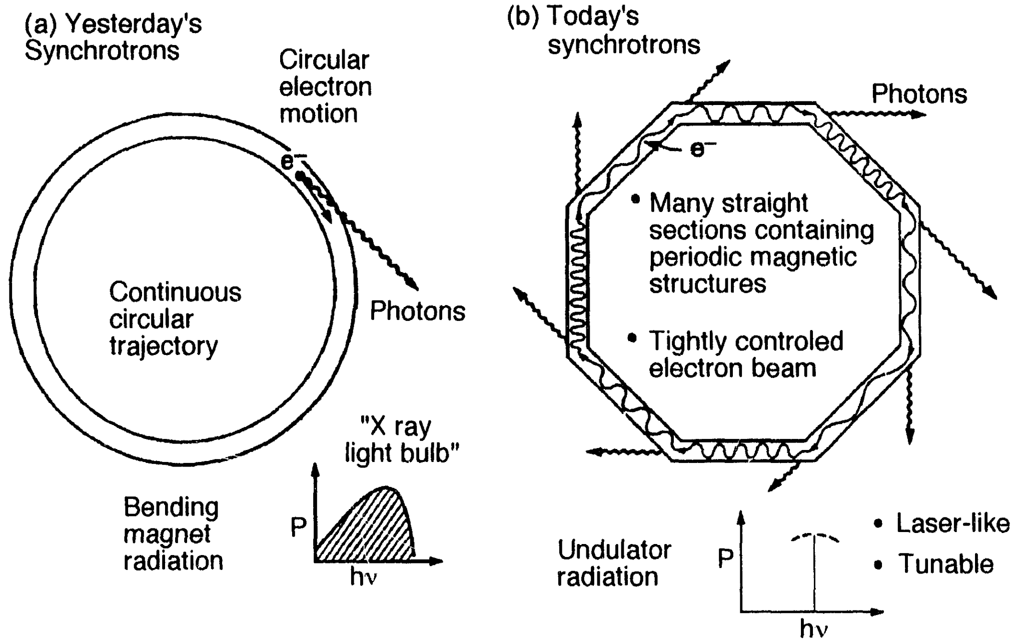


Figure 1. Earlier-generation synchrotron-radiation facilities (left) compared with third-generation facilities like the ALS. Straight sections in the newer facilities accommodate undulators, which produce partially coherent, tunable radiation.

The development of an undulator capable of delivering vacuum-ultraviolet (VUV) light and x-ray radiation was hampered before 1979 because it was believed such an undulator would have to incorporate a complex magnetic structure based on electromagnets. The creative insight of Klaus Halbach of LBL changed this situation dramatically. Halbach showed that, in place of electromagnets, strong permanent magnets made from rare-earth elements and cobalt could be arranged in simple arrays to construct alternating-field devices. Such devices have the property that the field strength in the gap between the poles remains constant as the linear dimensions are reduced in scale. Hence short-period permanent-magnet insertion devices can be made (allowing more electron-beam oscillations in a given length), whereas devices based on electromagnets quickly run into coil heating problems as they are scaled down. All third-generation machines in the world including the ALS, APS, and ESRF are based on this permanent magnet concept.

Synchrotron radiation produced by the ALS has certain properties that, individually or combined, allow researchers to perform experiments not otherwise possible. Of these, the most prized characteristic is high brightness; meaning the light has a high photon flux per unit source area and per unit solid angle into which the source radiates. The spectral brightness of the light from third-generation machines is 2 to 4 orders of magnitude greater than existing facilities, which means that many experiments that depend on high brightness will now be possible for the first time.

Another advantage of ALS undulator light is that a significant fraction of the long-wavelength radiation is spatially coherent. The criterion for spatial coherence is that the product of the area of the light source and the solid angle into which it emits must be no larger than the square of the wavelength of the light. Although not as coherent as the visible light from most lasers, undulator radiation has much more coherence than ever before available in the VUV and soft x-ray regions of the spectrum. One general virtue of coherent radiation is the ability to focus. For example, a Fresnel zone plate can focus a coherent beam of soft x rays to a spot with a radius approximately 1.2 times the width of the outermost zone (Figure 2). With state-of-the-art microfabrication techniques, such as electron-beam holography, it is possible to make zone plates with outer-zone widths of about 300 Å. This capability can be exploited in scanning or imaging systems to generate spatially resolved information with comparable resolution. Right now the finest source of high-resolution zone plates is here at LBL's Center for X-Ray Optics led by Dave Attwood.

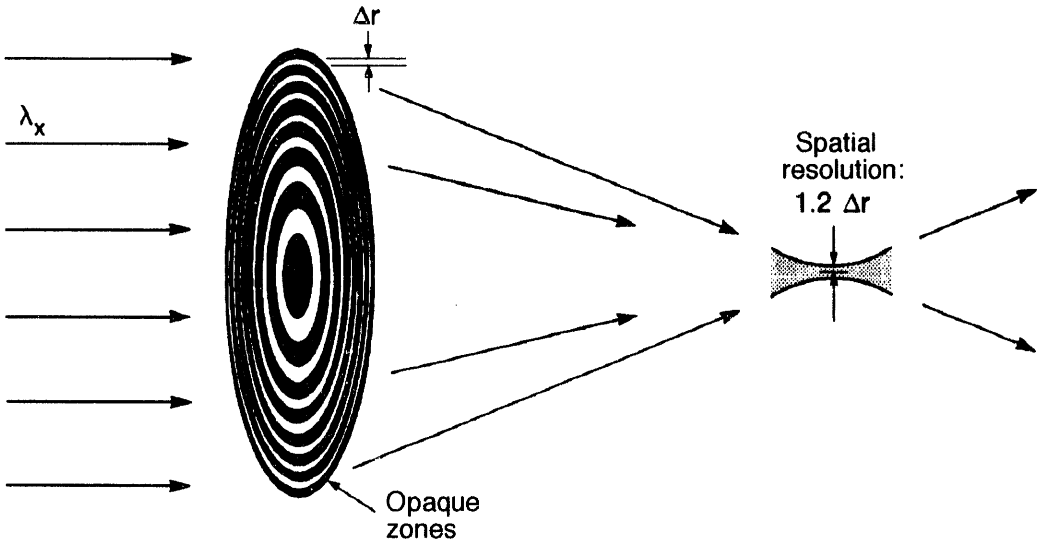


Figure 2. Fresnel zone plate lens for diffractive focusing of x rays.

You can see the progression. We built the ALS because it uses undulators, has high brightness, and has tremendous scientific opportunities for finely focused beams. As a result, even before we opened our doors for business we had ten different user groups planning to build microscopes for use at the ALS, with many more expected in the future (Figure 3).

Beamline	Photon Source	Type of Microscope	Application
6.0	U3.9 Undulator	Scanning (2)	Biological and Materials Sciences
6.1	Bend Magnet	Zone Plate Imaging	Biological and Materials Sciences
7.0	U5 Undulator	Photoemission Imaging	Surface and Materials Sciences
		Zone Plate Scanning (fluorescence)	Surfaces, Materials Sciences, and Polymers
		Zone Plate Scanning (photoemission)	Surface and Materials Sciences
8.0	U5 Undulator	Zone Plate Scanning	Surface and Materials Sciences
10.3	Bend Magnet	Microprobe (2)	Materials Sciences
11.0	Elliptical Wiggler	Spin-polarized Photoemission	Magnetic Materials

Figure 3. Microscopes planned for use at the ALS during the first few years of operations.

Next I would like to talk about the exceptional progress of the ALS during the last year. We injected electrons into the storage ring for the first time on January 14 and by the end of March we had stored 290 mA of current in the ring—exceeding the project baseline requirements. We had completed the project on time (and on budget), and our transition from project to operational facility took place on April 1. On that day the ALS project officially became the ALS Center, a DOE national user facility. The credit for the incredible success of this project belongs to hundreds of people, but I would especially like to thank Jay Marx. Jay was ALS project director from June 1987 to October 1992; in which time he organized the project, built the team, and led it to the brink of completion. He established the teamwork and cooperative relationships on which our current accomplishments are based.

The machine operates as a textbook storage ring; you could teach accelerator physics in the control room—it's that good! We have already met or exceeded all but one of the major specifications for the accelerator systems:

- Injector:
  - Linac .... 50 MeV
  - Booster .... 1.5 GeV, 1 Hz
- Storage Ring Optimum Energy .... 1.5 GeV
- Maximum Current (multibunch) .... 400 mA (460 mA achieved)
- Maximum Current (single bunch) .... 7.6 mA (27 mA achieved)
- Horizontal Emittance .... $< 10^{-8}$ m-rad
- Time Structure (2 sigma) .... 20-50 psec
- Variety of Operating Modes .... multibunch, few bunch, single bunch
- Lifetime .... > 6 hours (10h @ 100 mA)
- Variable Energy 1.0 to 1.9 GeV .... (coming soon)
- High Position and Angular Stability

Figure 4 shows an injection that was done at the end of April and illustrates how rapidly we can inject and store beam in the machine. When you are in the control room and looking at the current, you don't see the number changing over a normal attention span. Also the beam is very stable—no flickering or jumping around. We have successfully done every conceivable kind of bunch pattern imaginable—a far from trivial achievement which requires nanosecond-or-better timing.

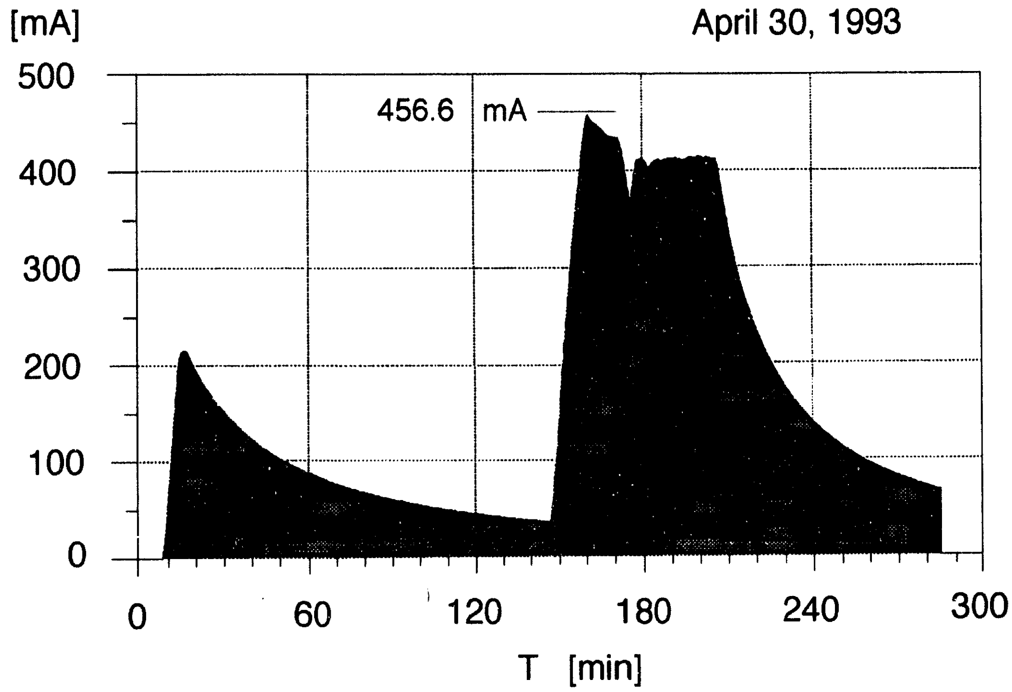


Figure 4. Current of the electron beam in the ALS storage ring recorded on April 30, 1993.

After the highly productive accelerator commissioning, we scheduled a three month summer shutdown to prepare for the start of user experiments. Several beamlines and two undulators were installed on the experimental floor, the storage ring's vacuum system was fully baked, and every critical component was realigned. Again, this was not a trivial exercise. If you look carefully at the photo in Figure 5, you can see small fittings called fiducials on the four top corners of the magnet enclosures. These fiducials are a critical part of the ALS survey and alignment system illustrated in Figure 6. Figure 7 shows one of the ALS crews performing a survey and alignment. Their measurements generate a set of Cartesian coordinates (u, v, and w) in the ALS local coordinate system for each fiducial, which specifies the exact location for the component being surveyed. Three fiducials are required for placing an object in space with 6 degrees of freedom, but four fiducials are desirable for redundancy, allowing a check. Fiducials must be configured to accept an optical target for direct sighting with an optical instrument, and a "tooling ball" for mechanical contact and measurement.

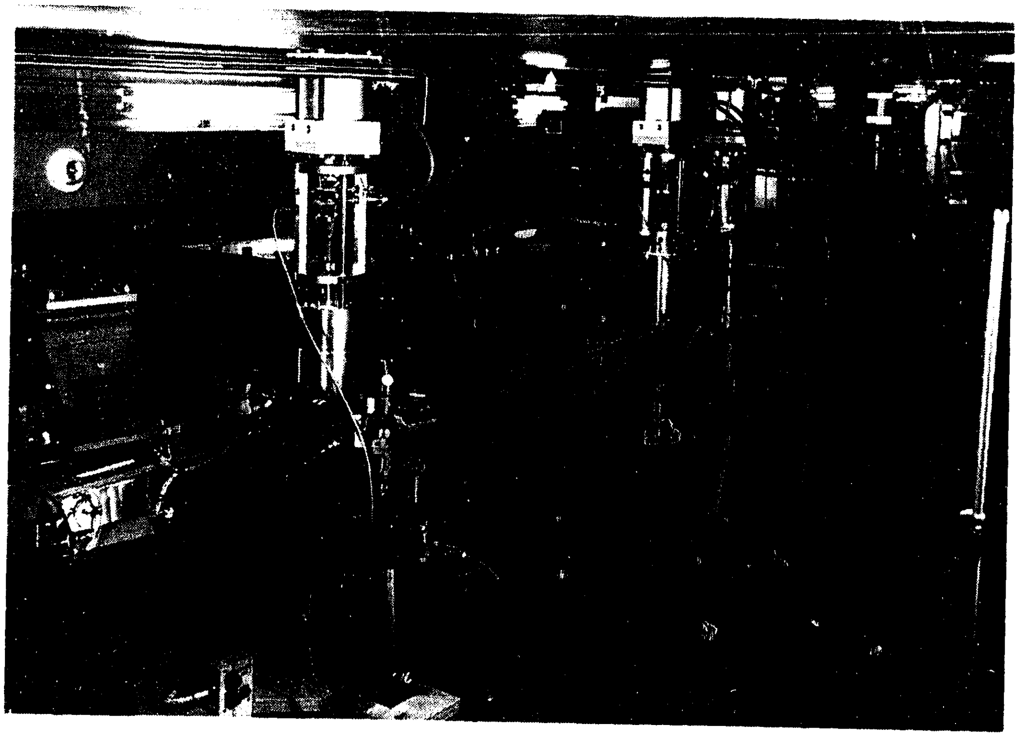


Figure 5. Critical components in the ALS storage ring and beamlines contain fiducials which are used to precisely align the equipment. You can see several fiducials on top of the magnet enclosures in this photo taken inside the storage ring.

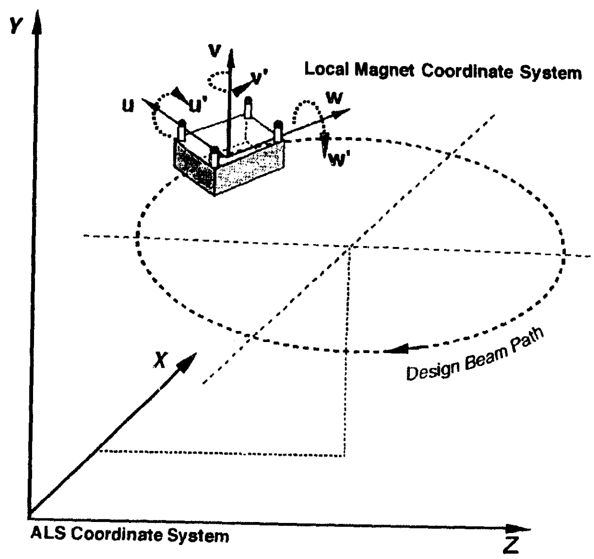


Figure 6. Diagram of the ALS local and global coordinate systems.

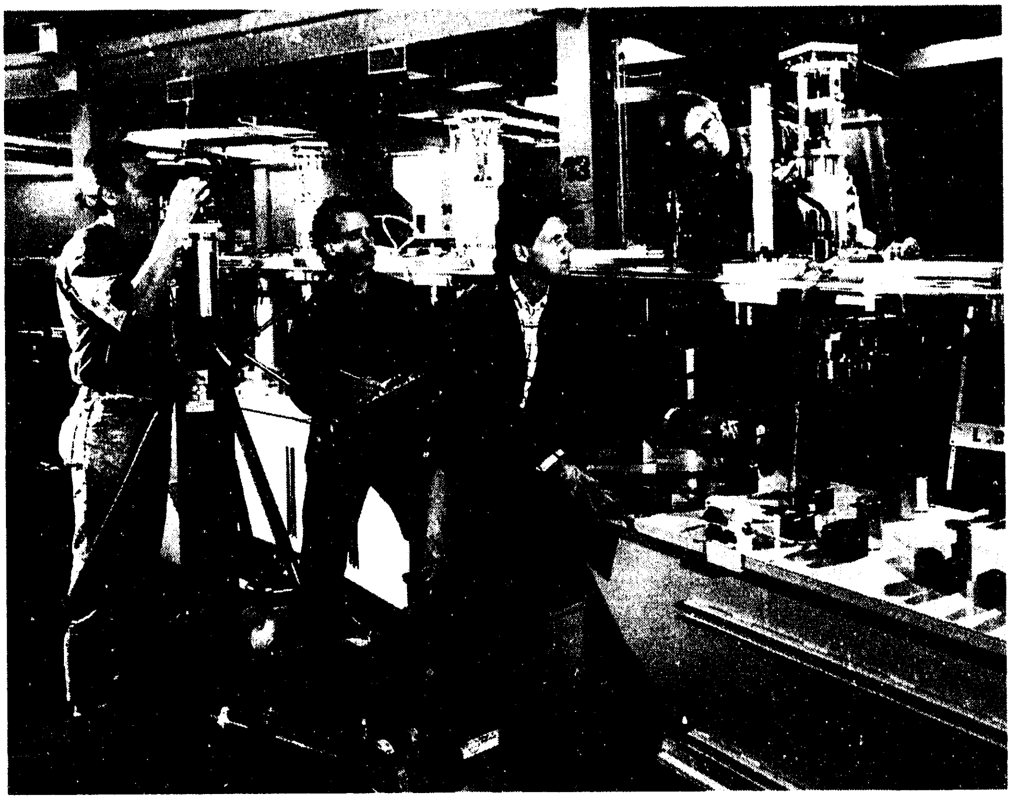


Figure 7. A survey and alignment team at work at the ALS.

The original specification called for every one of the over 200 storage-ring magnets to be aligned within 150 μm. And with a storage ring circumference of 200 m this is a challenge! Every critical component in the ring was realigned during the summer shutdown and Figure 8 illustrates the amazing result. The x axis is the sector number of the storage ring and the y axis is the average distance in mm from the ideal magnet position in the horizontal plane. (Note that the entire measurement scale only ranges from ± 1 mm.) The black squares are the survey errors after the realignment and you can see the remarkable result—the magnets are now aligned within 100 μm rms. The interesting thing is that when the machine was first turned on, the corrector magnets did not have to be used at all: the orbit was flat with no corrector magnets. Those of you that work at synchrotrons know that just doesn't happen! The open boxes in Figure 8 are the magnets' deviations from the ideal position in 1992. As you can see, there was a bulge in the machine of about 1 mm out of 200 m. I thought that was pretty good, but it turns out this is actually a significant distortion of the machine and has to be corrected. We decided this "dip" was due to the tons of concrete shielding that were used to complete the storage ring, the weight of which probably caused the building to slip slightly.

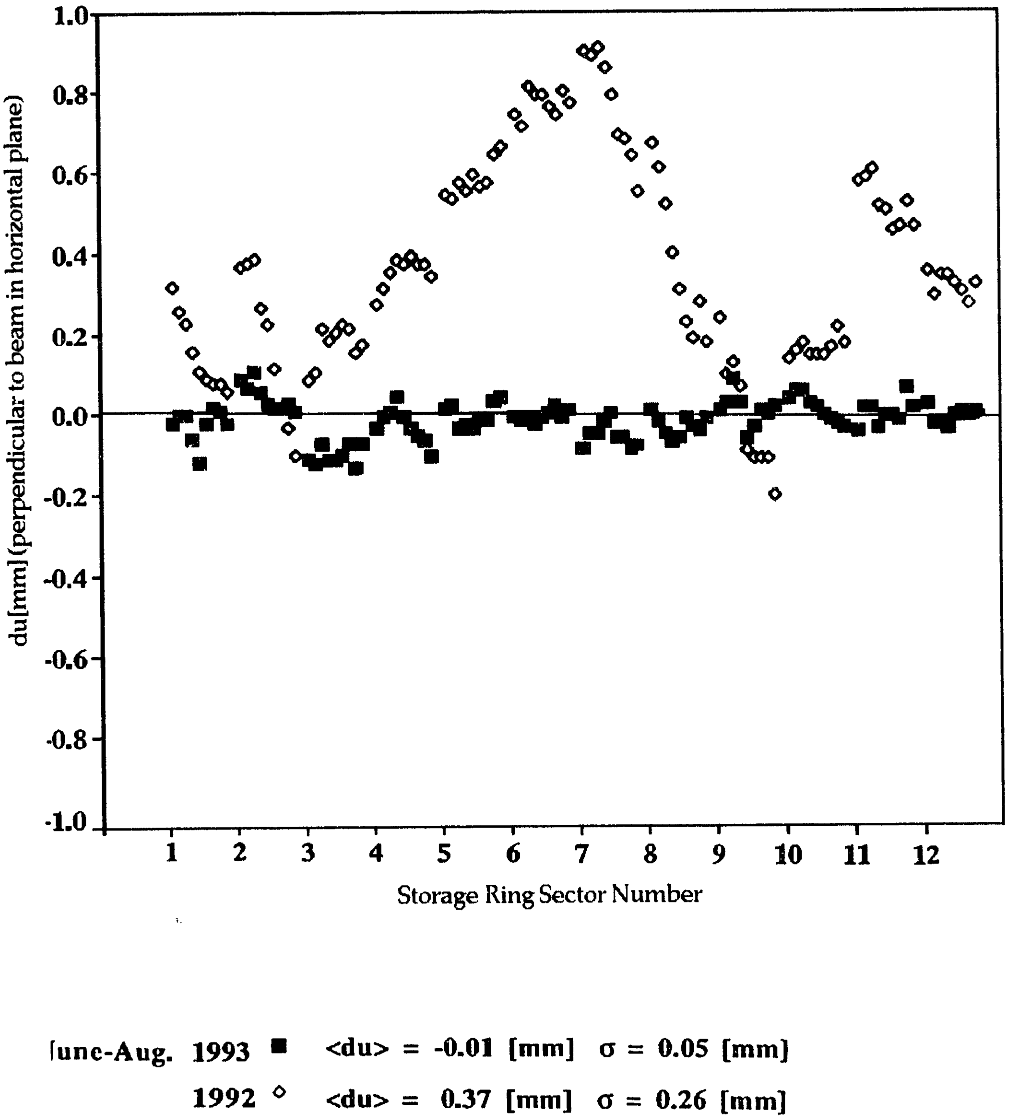


Figure 8. Each magnet in the storage ring was realigned during the summer shutdown period. The solid rectangles in this graph show that the magnets have been aligned within the specification of ± 0.150 mm.

Figure 9 shows one of the 5-cm-period undulators being *very carefully* installed in the storage ring during the shutdown period. At the start of the ALS project, you couldn't buy one of these things that would meet the specifications we needed. We had to develop the technology ourselves and invest an enormous number of man-hours worth of work. The result is a state-of-the-art device that meets all the design parameters we specified.

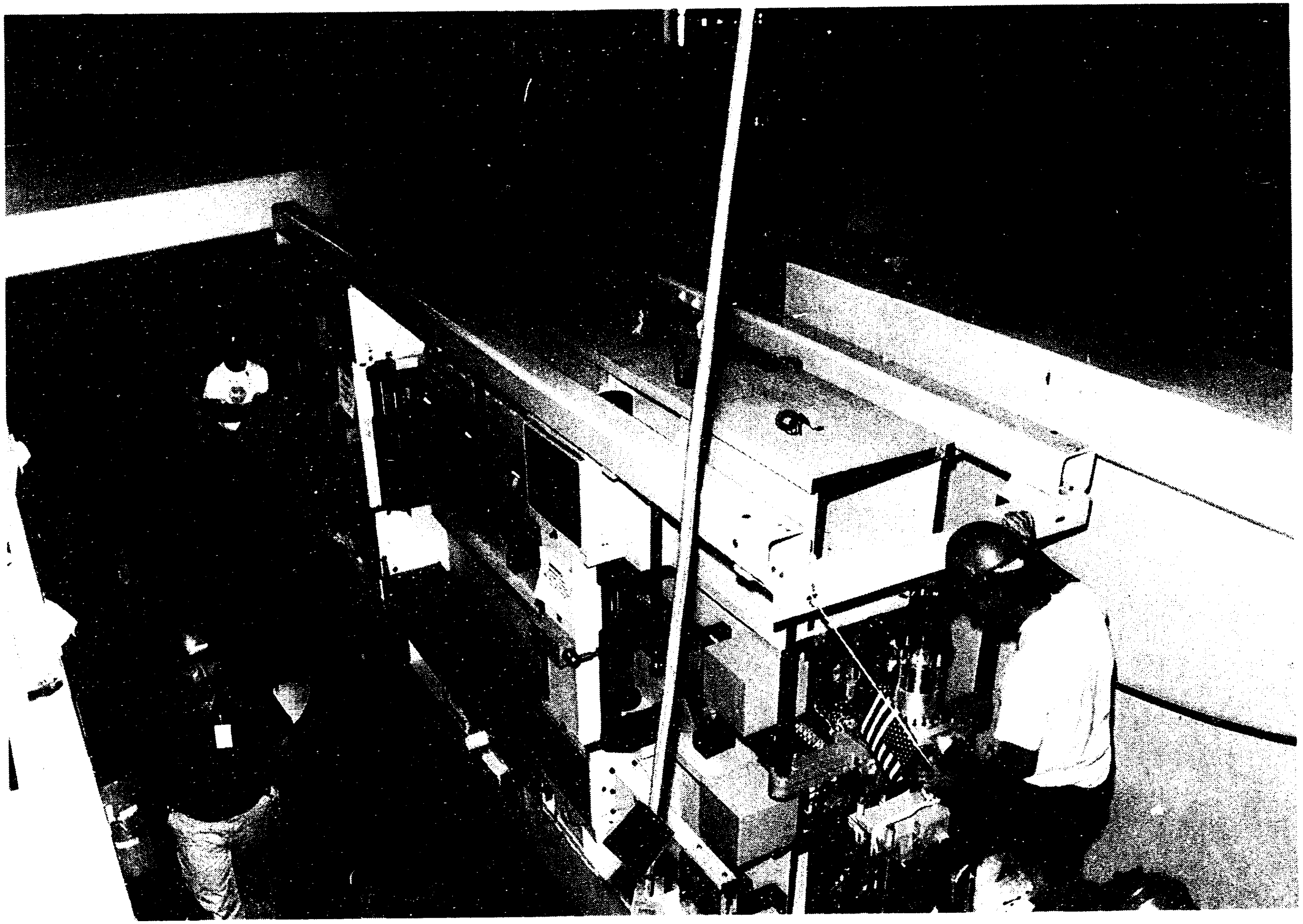


Figure 9. The first ALS U5.0 undulator was installed in the storage ring on May 7 with only inches to spare. The 4.55-meter magnetic structure along with its support structure, a combined weight of nearly 25 tons, was lowered into the ring after parts of the concrete shielding were removed. The second U5.0 was installed in June.

One of the consequences of undulators is that you generate a lot of power and the optics have to handle this heat load without distorting the focused image. Also they have to preserve the quality of the photon beam, which is smaller than some laser beams—otherwise we have wasted our time building the machine. Figure 10 is a prototype of an ALS-designed diffraction grating. You can see the water-cooling channels—a technology that was developed at the ALS. Today you can go to an outside company and order one of these things, but when we started this project they didn't exist. Wayne McKinney in the ALS optics group led the effort to develop and transfer this technology to industry.

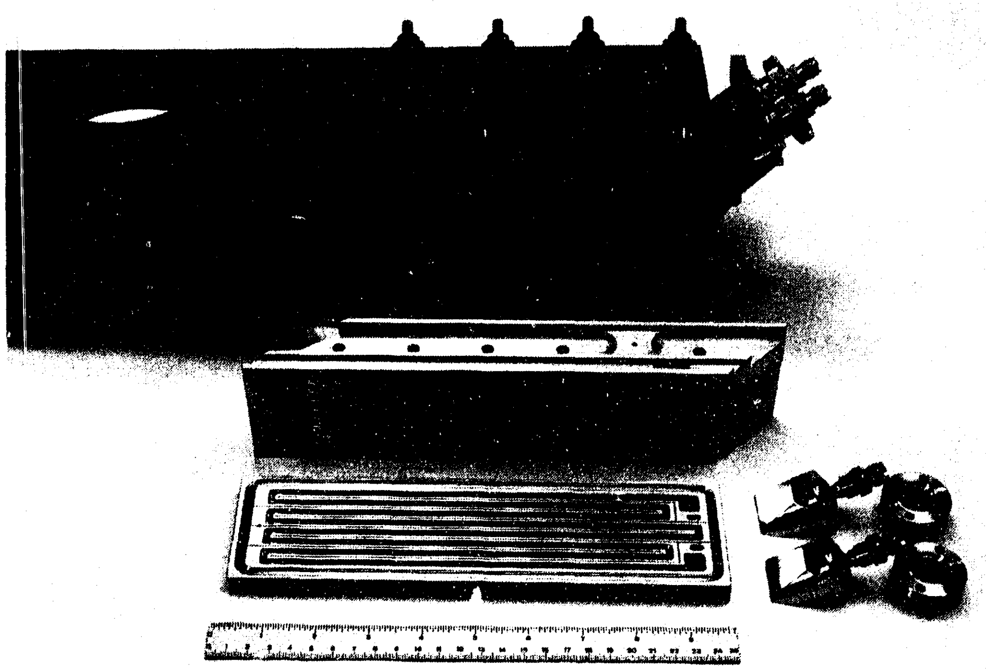


Figure 10. Water-cooled grating assembly for a beamline monochromator.

When the shutdown was over, we stored beam in a matter of hours after resuming accelerator operations. In fact, the time between turning on the radio-frequency system and magnets and getting the first stored beam was about one hour, and the next day we put 200 mA in the machine. However the real excitement started on October 4 when we delivered the first light to a user experiment: the CXRO x-ray microprobe beamline. Al Thompson led the development of this beamline, and I will let Al and Howard Padmore, head of the ALS Experimental Systems Group, tell you more about the first beamline in their talks this afternoon. Two weeks later, on October 18, a transmission grating spectrometer began recording undulator spectra on Beamline 7.0. And the diagnostic beamline was commissioned shortly thereafter, allowing the first measurements of electron beam size. The rapid restart of the accelerator system after a major shutdown, and the amazing progress in beamline commissioning, demonstrate that the ALS team is truly the world leader in the business.

Naturally the observation of the first undulator light was one of the most important "tests of readiness" for the ALS. We actually built a special instrument, called a transmission grating spectrometer (TGS), to measure the spectrum of the undulator beam. The TGS is used to disperse and focus radiation from the undulator onto a slit and detector. By moving the slit, the analyzed wavelength can be change to produce a spectral scan. Figure 11 shows the instrument before it was installed. The measurements taken so far show that the ALS has indeed passed the "test," as they indicate the undulator is behaving as predicted, giving excellent higher harmonic performance.

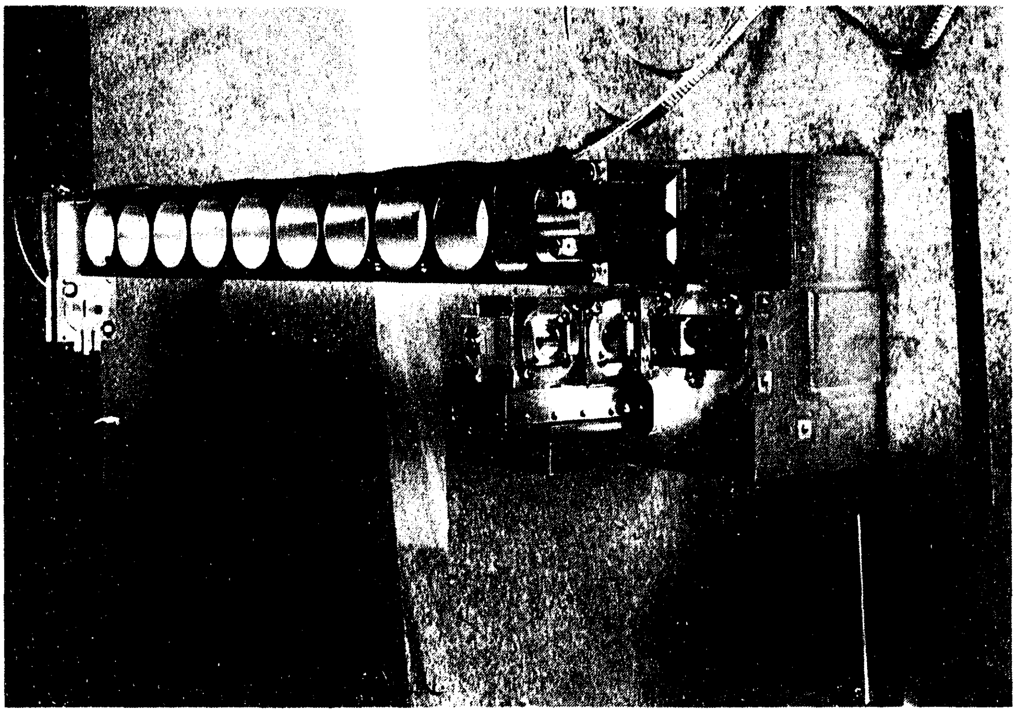


Figure 11. The ALS designed and constructed this transmission grating spectrometer to measure the undulator spectrum.

One of the last things that we turned on very recently, aside from the first undulator beam, was the diagnostic beamline. It is another example of how difficult it is at the ALS to do things that would seem to be ordinary, trivial things. The diagnostic beamline (Figure 12) is basically an x-ray camera that was built to image the electron beam. That sounds pretty trivial. Other facilities use TV cameras and visible light to image the beam, but the ALS beam is so small that you can't see it with visible light. All you see is a diffraction-limited blur. You need to have a very high-resolution x-ray camera to resolve the beam. So what sounds like a trivial project at first, ends up being quite an engineering challenge.

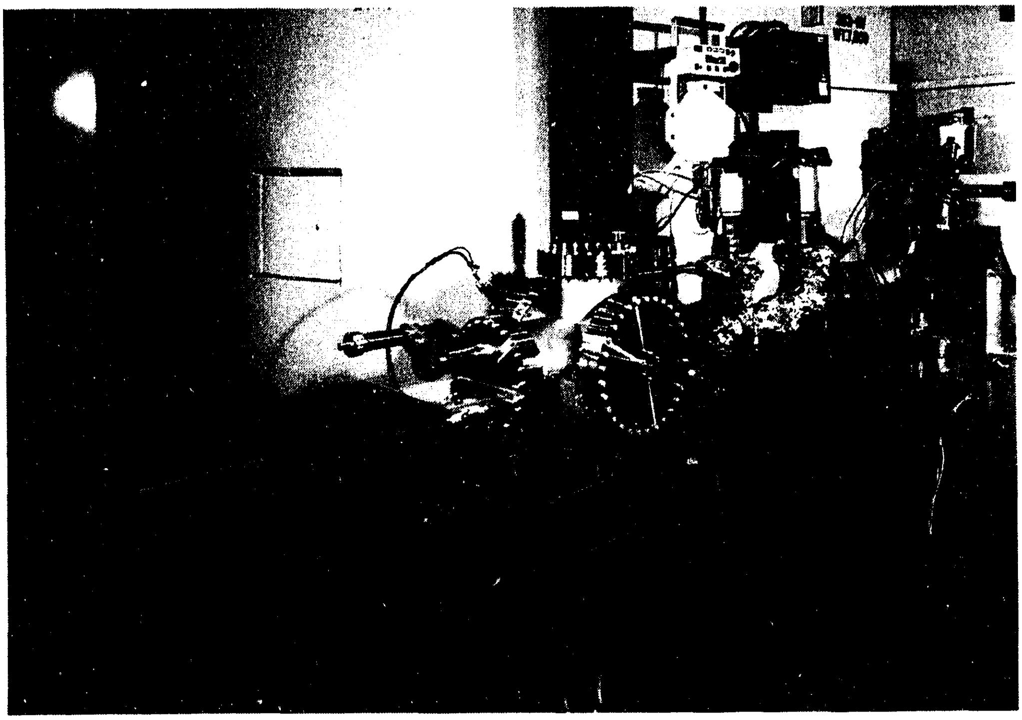
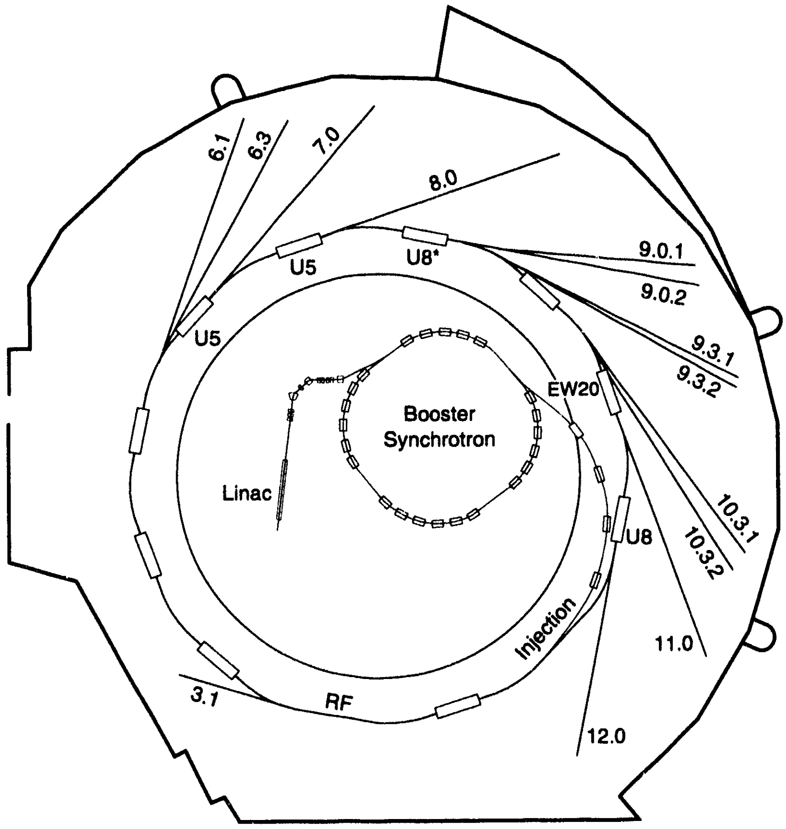


Figure 12. The diagnostic beamline provides precise imaging of the source and allows measurement of the transverse dimensions of the beam. It also collects information about the positional stability of the beam and the timing of the electron bunches. The data is used to optimize the orbit and size of the electron beam in the storage ring.

In conclusion, I would like to talk about our plans for the first few years of operations. We expect to complete several more beamlines in the coming year, with a goal of at least 12 operational beamlines by the end of 1995 (Figure 13). A third undulator, U8.0, will be installed in sector 9 of the storage ring during a short shutdown scheduled for late spring 1994. One of our most exciting projects, the design and construction of an elliptical wiggler (EW20), is well underway. The elliptical wiggler project was determined to be so important that we are going ahead with it despite our limited resources—thanks in large part to support from the DOE and LBL. The elliptical wiggler generates circularly polarized x rays and, if you're in this business at all, you know that's the hot topic now—polarization control.

Going back to Figure 13, you can see that we have about 50% of the capacity of the facility that isn't developed yet. To fill in those areas with beamlines, we need to get more money. You can get a rough idea of how much money by knowing that one of these undulator beamlines costs about $5M to $10M. We have put together a strong package for the DOE called the ALS Beamlines Initiative to build more beamlines, but this will likely not be funded until 1996. In the meantime, we are working very hard to complete the initial set of beamlines.

The ALS project and our initial months of operations have been a tremendous success story; with the challenge of establishing a world-class scientific program now before us. I look forward to working with the user community, government, and industry to meet this challenge, and to continue to develop the unique capabilities of this facility.



* Will change to U10 in 1995

XBL 928-5341A

Figure 13. ALS beamlines planned for 1993–1995 operations.

The ALS Into the 21st Century

David S. Shirley

Pennsylvania State University
University Park, PA 16802

The Advanced Light Source provides uniquely superior new access to two decades of the electromagnetic spectrum. We stand now at a threshold similar to that provided by lasers in 1960. Let us pause at the threshold and see how we arrived here, then look ahead.

I'll begin historically. My first real interest in synchrotron radiation started in 1968, when I learned of the possibilities for the SPEAR ring at SLAC, and developed further when I helped SLAC win NSF support for the SSRP project, later SSRL, a first-generation, parasitic source.

In 1976 I served on the NAS/NRC committee to assess the national need for dedicated synchrotron radiation sources, and we recommended state-of-the-art second-generation rings which unfortunately were not designed optimally for insertion devices. I became fully aware of the potential of permanent-magnet-based insertion devices—Klaus Halbach's great contribution—in 1980, and asked our accelerator experts to think about free-electron lasers for short wavelengths. This moved slowly, and in 1981 LSBL also entered a partnership with EXXON and SSRL to develop a beamline based on the famous 54-pole wiggler.

In April 1982 I decided that the next step was a 3rd generation light source, that the world was ready for such a source, and that LBL should build it. The soft x-ray range accessible to a 1.5-GeV ring (then 1.3 GeV) seemed more scientifically promising than a 5-6 GeV ring, and the proximity of the PEP ring at SLAC made the latter redundant, anyway. I picked the name "Advanced Light Source" because it is advanced, and also to complement our advanced materials center. It proved to be a robust choice, and was emulated by the APS and ANS projects!

By mid-1985 we learned that the ALS would be funded in the FY 1987 budget, and that APS, RHIC, and ANS would follow at other labs, in an integrated "facilities initiative," as I had advocated earlier. The Users' Association was already formed, and the rest is history.

The ALS design has stood the test of time, having now been cloned in 8-10 other projects around the world, with few changes. This shows that the technology was ready for a 3rd-generation source.

We learned from this experience to stick with and develop a good idea, but also to be prepared to invest some time: 11 years in this case! Also, plan ahead. It is time now to design the 4th generation sources, short-wavelength free-electron lasers.

The ALS will not be unique for long, and it is important to develop optimal beamlines and end stations worthy of a 3rd-generation source. The ALS must also be user friendly and attractive to the broad academic science community, to overcome the inertial barrier of moving to accelerator-based research.

We know the wonderful new radiation parameters that the ALS provides. I'll eschew listing them and only note that light in the soft x-ray range gives new access to the length scale of the light itself, and that of photoelectrons which the light excites. Thus the 1-1000 Å scale is covered in direct, new ways, from atomic sizes to the 0.1 μm range: i.e., through the nanometer region. Nanofabrication, nanostructures, micromachining, subcellular structure, all lie in this range, and just as the 21st Century will be the century of biology, of information, and of the environment, so will it also surely be the century for understanding matter on the nanometer—or mesoscopic—scale, where classical and quantum properties meet.

On the more familiar atomic scale, core levels of all the elements will be accessible, and selective excitation will make state-to-state chemistry a reality, along with other dynamic phenomena, microanalysis, x-ray imaging, high-resolution work, magnetic circular dichroism, spin phenomena, etc.

The effective development of these fields will require more sophisticated instruments downstream: 2π detectors, for example, in my own field of photoelectron diffraction and holography, interferometry to enhance resolution, and the use of synchrotron radiation for both the pump and probe pulses to take advantage of the natural timing sequence in the machine.

All these improvements and many more are taking shape in our imaginations, and will be on the floor as we move ahead into the new world which these light sources open up for us. Of course the real new paradigms will only follow later, as we learn to work in that world. An exciting future is in store!

Report From The DOE

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I am happy to be here, and I would like to welcome you on behalf on the DOE. The construction and initial operations of the ALS have been a remarkable success—due to the Lawrence Berkeley Laboratory and the ALS Staff in particular. This past spring when we presented the case to obtain the Secretary's approval to begin the operation of ALS, we were asked as to what we attributed the success of the ALS project. My answer was very simple—get very good and dedicated people, give them the tools to do the work, and stay out of their way! We are very proud of the job done by Jay Marx and Brian Kincaid and Ron Yourd and Alan Jackson and indeed, by everyone on the ALS Staff. I should also like to acknowledge the role of several predecessors at DOE, namely Don Stevens, Lou Ianniello, and Chalmers Frazer. Iran Thomas, as Division Director of Materials Sciences, has been a vigorous defender of the ALS.

Last year, I noted that we had entered the "advent" period as we anticipated the commencement of ALS operations—and that we were all waiting to see what kind of toys would appear under the storage ring!

We are beginning to see some of these toys appear on the floor of the ALS. At this time, we seem to have funding commitments for five insertion device beamlines, for more bending magnet beamlines. We anticipate that other commitments will be made in the coming year from a variety of sources. One of the very interesting and exciting developments has been the coming together of the Basic Energy Sciences and the Office of Health and Environmental Research to support the construction of an elliptically polarized wiggler beamline which will provide circularly polarized photons to study magnetic structures and helical molecules important in biology and chemistry. These funding commitments are in place and work is underway.

Even in view of these successful efforts, we still have a long way to go before we will have the ALS fully instrumented. However, I must tell you that I am very encouraged by the beamline commitments that have been made so far, and it is my belief that more will follow in the coming year.

The FY 1994 DOE budget has not yet been fully settled at the program level. In fact, I would remind you that we have to be in this effort for the long haul. Persistence is essential! I also noted last year that it may even turn out be a good thing that we couldn't support all requests immediately—so that newly conceived ideas such as an elliptical wiggler can be started in a timely way. The elliptical wiggler <u>will</u> be developed at ALS and should be ready to go in spring of 1995. There may be other such devices waiting the wings.

On that note I will stop. I am really looking forward to the implementation of some of the ideas made possible by the ALS, and I hope you will have a good meeting and a good year.

Scientific Program At The ALS

Neville Smith

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The speaker has been Chairman of the Program Review Panel of the ALS for five years, and is also Scientific Program Head Designate of the ALS.

As the start of a "get acquainted" process with the User community, the speaker described his scientific background, starting with his introduction to the infant technique of photoemission spectroscopy in Bill Spicer's lab at Stanford, continuing with contributions to angle-resolved photoemission, and culminating with experiences of spin-polarized photoemission on the U5U undulator beamline at Brookhaven. Photoemission has progressed over this period from being a relatively primitive benchtop experiment to a sophisticated technique requiring third-generation synchrotron radiation sources. The rate of progress shows no sign of slackening.

The Program Review Panel (PRP) is a nine-member body which advises the ALS management on major decisions. Its activities were described, especially the momentous meeting of November 1989, when the PRT proposals were evaluated and recommendations were made on the allocation of the $12M trust fund. It was stressed that those PRT's that did not receive funding should not take this as a negative comment on the quality of their proposal.

With regard to the scientific program at the ALS, the speaker endorsed the dazzling vision expressed earlier by Dave Shirley and the $63M wish list of Brian Kincaid. It was asserted, however, that organizations like the ALS are really led from the bottom up, and that the vision and impetus to carry through that vision must ultimately come from the Users. The speaker closed by expressing his enthusiasm to work with the Users in coming years.

Plans for Industrial Use of the ALS

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The Advanced Light Source, completed in March 1993 for the Department of Energy(DOE) by Lawrence Berkeley Laboratory (LBL), is the United States premier third-generation synchrotron light source. This multi-user facility not only will be used in forefront basic scientific research (its main mission), but can also become an integral part of the technological infrastructure serving industry.

Synchrotron light has already proved useful in advanced manufacturing, process control and industrial knowledge base development, and is used by industry worldwide. Due to advances in solid state electronics, the 20th century brought a course of increasing miniaturization from tube radios, bulky TVs and room sized computers to Walkmen, flat panel displays, and laptop computers. The next round of miniaturization is underway—the round of nano electronic and optical technology and micro-electromechanical devices (micro machines). Synchrotron light will play an important role in the next round of miniaturization and understanding of systems on a molecular scale. Already with the help of synchrotron light, new pharmaceutical and chemical catalysts are being designed rather than discovered; machines, sensors and actuators the size of the human hair and smaller have been fabricated for smarter and lighter automobiles, airplanes and satellites; and materials fabricated for biotechnology and electronics can be analyzed on a near atomic scale.

Micro machines

On August 3, 1993, LBL held the first workshop on deep etch x-ray lithography for high aspect ratio micro electromagnetic and mechanical structures (HAR-MEMS Workshop - Proceedings in print). In the first process (LIGA), first used by KfK and first commercialized by Microparts[1] in Germany and now also being expanded at the University of Wisconsin,[2] metal structures of 0.1-.5 mm height are formed with sub-micron accuracy. A Participating Research Team led by Keith Jackson of the LBL Center for X-Ray Optics has been formed of groups interested in process and device research. At the workshop, the Berkeley Sensors and Actuators group from the University of California at Berkeley presented several applications that require or could benefit from deep etch x-ray lithography.

To support the emerging community, three beamlines and support facilities are planned:

1. A branchline fitted with aspheric optics for normal incidence exposure of large areas (100 mm).
2. A branchline fitted with a planar mirror for development of exposure systems and for variable high energy cutoff for very thick resist exposures.
3. A white radiation beamline for resist exposure modeling and general research use.

This beamline system is very similar to the facility planned by the Louisiana Tech University Institute for Micromanufacturing at the Louisiana State University Center for Advanced Microstructures and Devices.

Along with the beamlines, basic facilities will be provided for mask fabrication; resist application, preparation and development; and electroplating in gold, nickel and copper. The first experiments will be performed on a borrowed branchline to the Microprobe experimental station (Beamline 10.3) using white light.

Protein Crystallography

California is also a center for biotechnology companies—some engaged in rational pharmaceutical design, a term that describes the process where pharmaceuticals are designed based on detailed structural and functional information rather than discovered by trial and error. With x-ray crystallography, scientists have solved the structure of common cold,[3] HIV[4] and influenza[5] surface proteins and this information is being used to design pharmaceuticals to attack these viruses. Some of these pharmaceuticals are now in clinical trials.

At LBL, the group headed by Sung-Hou Kim of the Structural Biology Division has had excellent success using synchrotron-based crystallography. Kim's group has deduced structural changes in proteins that lead to proliferative growth of cancer cells.[6] The c-H-*ras* oncogene protein which plays a key role in the pathway for chemical signals that regulate cell growth, undergoes a slight molecular change that inhibits the return of the protein to the "off" state, thereby leading to unregulated growth. Work in the industrial sector is underway to exploit this new understanding for the control of cancerous growth.

There are of order 50,000-100,000 eucharyotic proteins and many bacterial and many viral proteins left to solve (not all amenable to crystallization, however).

After years of effort, only 2,000 protein structures are now registered in the protein structure data base maintained by Brookhaven National Laboratory. A great deal of work remains to be done to reap the full commercial and human benefits of synchrotron based protein crystallography. The Biosync committee has issued a comprehensive report outlining the need for at least 18 rapid data collection beamline stations by the year 2000 to meet demand.[7] Synchrotron light sources are uniquely capable of rapidly and accurately generating many needed crystallographic data sets.

The addition of a wiggler insertion device and "user friendly" end stations makes the ALS fully competitive in protein crystallography and can serve the nearby and established biotechnology community 250 days per year.

Analytic Services

In early 1992, LBL sponsored a workshop on the use of synchrotron light to provide analytic services for industry.[8] The emphasis was on photoelectron spectroscopy, although x-ray photoabsorption and fluorescence were addressed. Quantitative analysis of the elements using electron spectroscopy for chemical analysis (ESCA) has the advantages of chemical state and surface state sensitivity. Beamlines with analytic capability that start operation between now and 1995 include high resolution x-ray microscopy (bend magnet Beamline 6.1), spectroscopy facilities (bend magnet Beamline 9.3.1), spectromicroscopy facilities (undulator Beamline 7.0), a white light microprobe (bend magnet Beamline 10.3), and others that will form the core for general analytic services for industrial users.[9]

Conclusion

There is a growing awareness of the capability of light sources to contribute value to the economy. The industrial applications mentioned above were substantially developed in the late 70s and early 80s. During the 80s there was about an order of magnitude growth in publications related to synchrotron light. Given that the time delay from University research to industrial fruition is typically 10-15 years, we are now poised for an order of magnitude increase in demand from the industrial sector between now and the early 21st Century. With timely capital investment to produce industrial quality facilities and vigorous communications efforts we can meet that demand.

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Progress in Beamline Commissioning and Overview of New Projects

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October has been a month of extraordinary accomplishments for the ALS Experimental Systems Group. We have commissioned three of the beamlines planned for initial operations, and two more are close to completion. This success is due to the hard work and careful planning of the entire ALS staff, and they are all to be congratulated for their efforts.

This presentation describes the preliminary results from two of the newly-commissioned beamlines: the diagnostic beamline 3.1 and the undulator beamline 7.0. I will also give a short overview of some of the new projects the ALS is collaborating on; including a branchline devoted to chemical dynamics studies, a protein crystallography beamline, and an elliptical wiggler.

The diagnostic beamline shown in Figure 1 produces a 1:1 image of the bending magnet source using broad-band x rays. The x rays are converted to visible light using a scintillator and imaged using a microscope and CCD camera. The machine-physics group will use the data collected on the beamline to study the stability of the stored beam as well as to measure the horizontal and vertical beam sizes and to deduce emittance and coupling. The beamline's imaging system employs two crossed spherical mirrors in a Kirkpatrick-Baez configuration that work at almost unity magnification to avoid distortion of the image due to spherical aberration. The mirrors are made of Glidcop™ (an alumina dispersion strengthened copper alloy) coated with nickel. The vertical mirror is water cooled to eliminate thermal distortion and has a grazing incidence angle of 1.5°; the horizontal mirror has a grazing incidence of 2.0°.

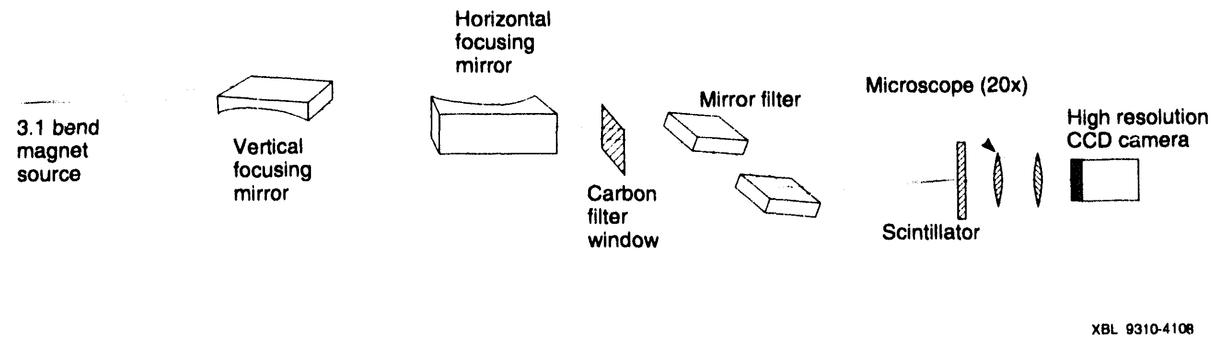

Figure 1. Path of the synchrotron light through the optical components of the ALS diagnostic beamline.

The two mirrors provide a high-energy cutoff of approximately 1 keV. The low-energy cutoff is given by a thin (5 μm) carbon foil which acts as a filter by passing light between 220 eV and the carbon K edge at 287 eV. The photon-energy bandpass from 220 eV upwards defines a diffraction-limited source size smaller than the real source. (The filtering-out of low-energy light is necessary to avoid a broadening of the image due to diffraction from the mirror-defined aperture.) A focused image of the source is produced on a bismuth-germanium oxide scintillator screen and the resulting visible image is then focused onto a CCD camera by a standard microscope. The resolution of the system is approximately 5 μm.

Figure 2 shows one of the first images of the stored electron beam obtained from the diagnostic beamline. The size of the beam is somewhat bigger than expected and is clearly enlarged by various instabilities. The image data collected by the beamline is transmitted to computers in the control room, permitting the operations staff to interpret the data to optimize the performance of the storage ring. A notable feature of the beamline is its special shielding that allows it to be operated while the storage ring is being filled. This has already proved to be invaluable in studying injection processes.

- Assume .....
  10^{-8} m.rad horizontal emmitance
  10% coupling
  ∫v = 20.34 m, ∫h = 0.394 m, îp/p = 0.03

- Predicted beam size from an X.1 bend is
  Vertical 142 (335) µm
  Horizontal 67 (157 µm)
  1 sigma (FWHM)

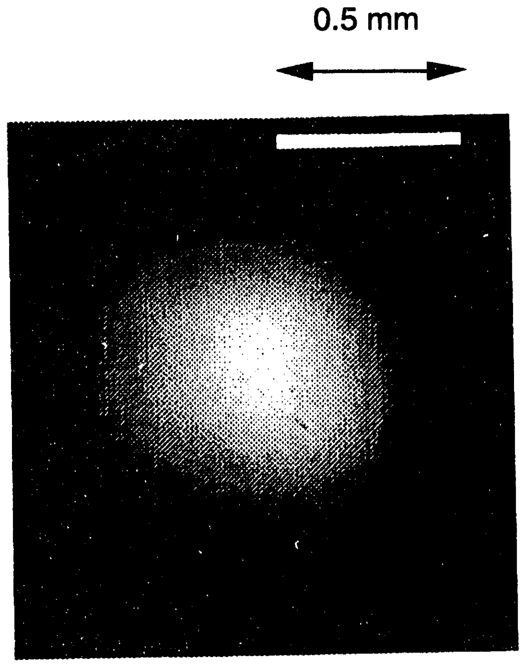

Figure 2. Image of the ALS electron beam collected by the diagnostic beamline on October 20, 1993—the same day the beamline was commissioned.

The diagnostic beamline worked within hours of being turned on for the first time; a testament to the dedication and expertise of all involved. I especially want to thank Ed Melczer, who had overall responsibility for this project, and Pat McKean for their efforts to complete the beamline in record time; and members of the Mechanical Engineering section led by Tom Henderson for their excellent support during the last few months. Figure 3 shows the beamline with some of the key members responsible for its design and construction.

Figure 3. The diagnostic beamline provides precise imaging of the electron beam. Key members of the design and construction team include (from left): Pat McKean, Ed Melczer, Arash Saffarnia, Ed Wong, and Rupert Perera.

Next I'd like to talk about the undulator beamline 7.0. As can be seen in Figure 4, the light from the 5-cm-period undulator is focused by a spherical vertical condensing mirror onto the entrance slit of the spherical grating monochromator. The horizontal beam-defining aperture is used to scrape off the sides of the undulator beam and can be adjusted by motor-driven grazing-incidence blades. The design of the entrance slit was one of the most demanding engineering challenges faced by the beamline engineering group as it is subject to a very high peak power density from the focused undulator source. The experimental requirements for spectral resolution meant that the width of the entrance slit had to be precisely controllable and adjustable between a minimum of 5 μm and a maximum of 200 μm. To meet the demanding design requirements, the Beamline Engineering Group led by Dick DiGennaro designed a unique flexure assembly that transfers the actuation forces to the slit blades.

Perhaps even more impressive was the engineering group's success in dealing with the thermal problems. To handle the high heat load, care must be taken in choosing the substrate material for mirrors and gratings and in designing the cooling-channel geometry to guarantee that optical imperfections are not dominated by thermal distortion. Again, Glidcop was selected for the substrate material for the mirror and gratings. It can be machined and brazed, which allowed the water cooling channels to be constructed as necessary to match the heat load and footprint of radiation.

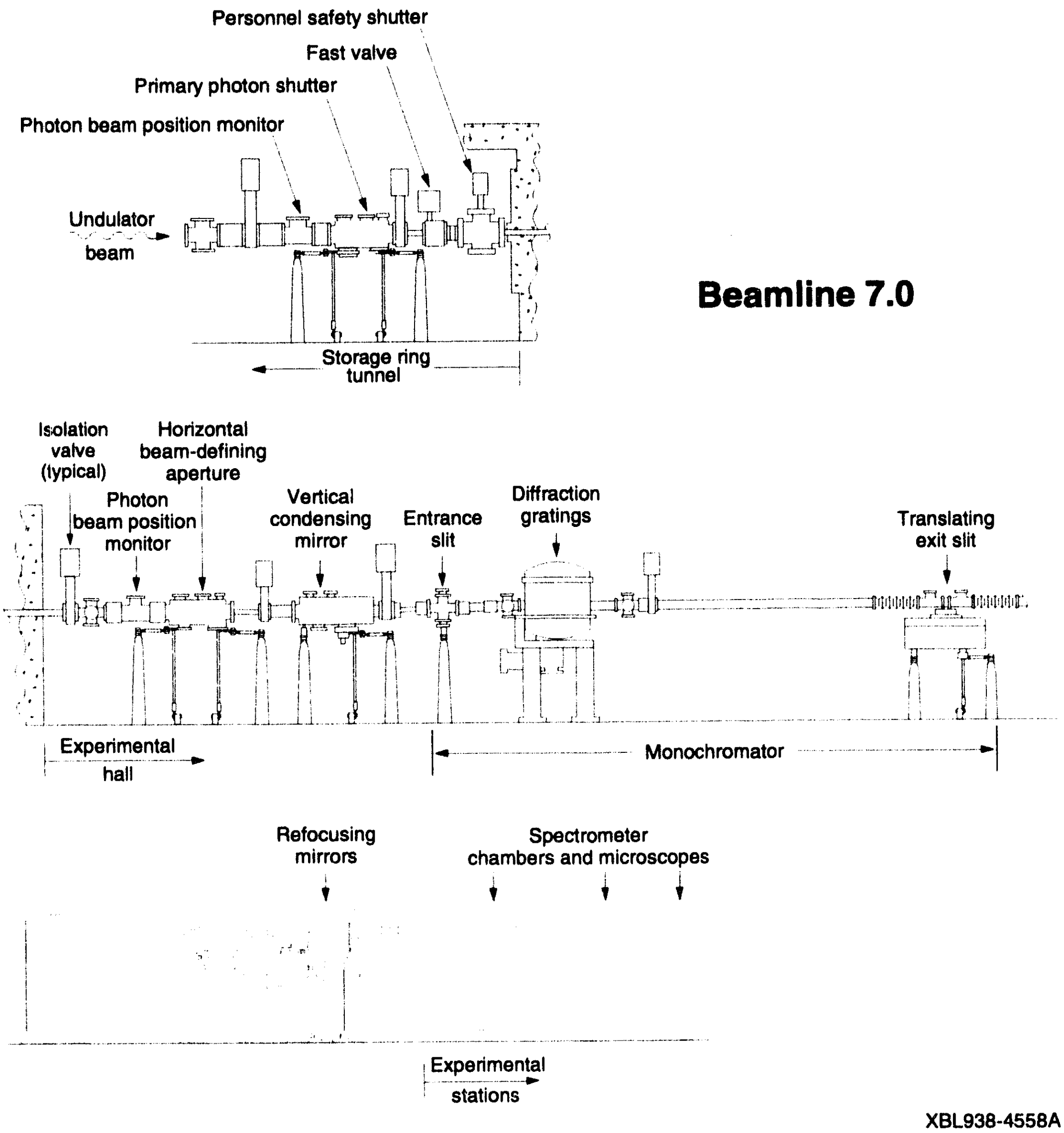

Figure 4. Schematic layout of Beamline 7.0.

The beamline's monochromator features three water-cooled gratings that rotate about an axis under computer control to scan the wavelengths. Light diffracted from the grating is focused onto the exit slit and a combination of crossed cylindrical mirrors focuses the light in the vertical direction from the exit slit to the sample, and in the horizontal direction from the source to the sample. The different exit slit positions given by the requirement for focusing the monochromator can be accommodated by the variable-radius vertical refocusing mirror. The radius of the mirror can be changed by bending the substrate and the focus can be placed in either experimental chamber, regardless of the position of the exit slit. The spherical grating type of monochromator, as well as the use of bendable mirrors incorporating integral flexural hinges, were pioneered by Malcolm Howells.

All the mirrors are now at the ALS and are undergoing testing in the metrology laboratory of Wayne McKinney and Steve Irick. The grating substrates are finished and qualified to the required figure and finish and are awaiting holographic recording and ion etching. We expect one complete set of high line density gratings to be delivered by mid November. The beamline front end, the horizontal beam defining apertures, and the monochromator are complete; and the exit arm of the monochromator including the slits and refocusing mirrors have yet to be installed. We expect completion of the beamline by early January.

Figures 5 and 6 show another engineering success story: the beamline's vertical condensing mirror and chamber. The whole mirror system is mounted on one flange, and the pitch can be controlled either with a micrometer or with a piezo drive. The idea of the piezo is that we will be able to sense the flux through the monochromator entrance slit and optimize it by servoing on the mirror angle. The bubble levels in the original sketch and engineering diagram in Figure 5 allow very accurate alignment of the mirror assembly after any movement.

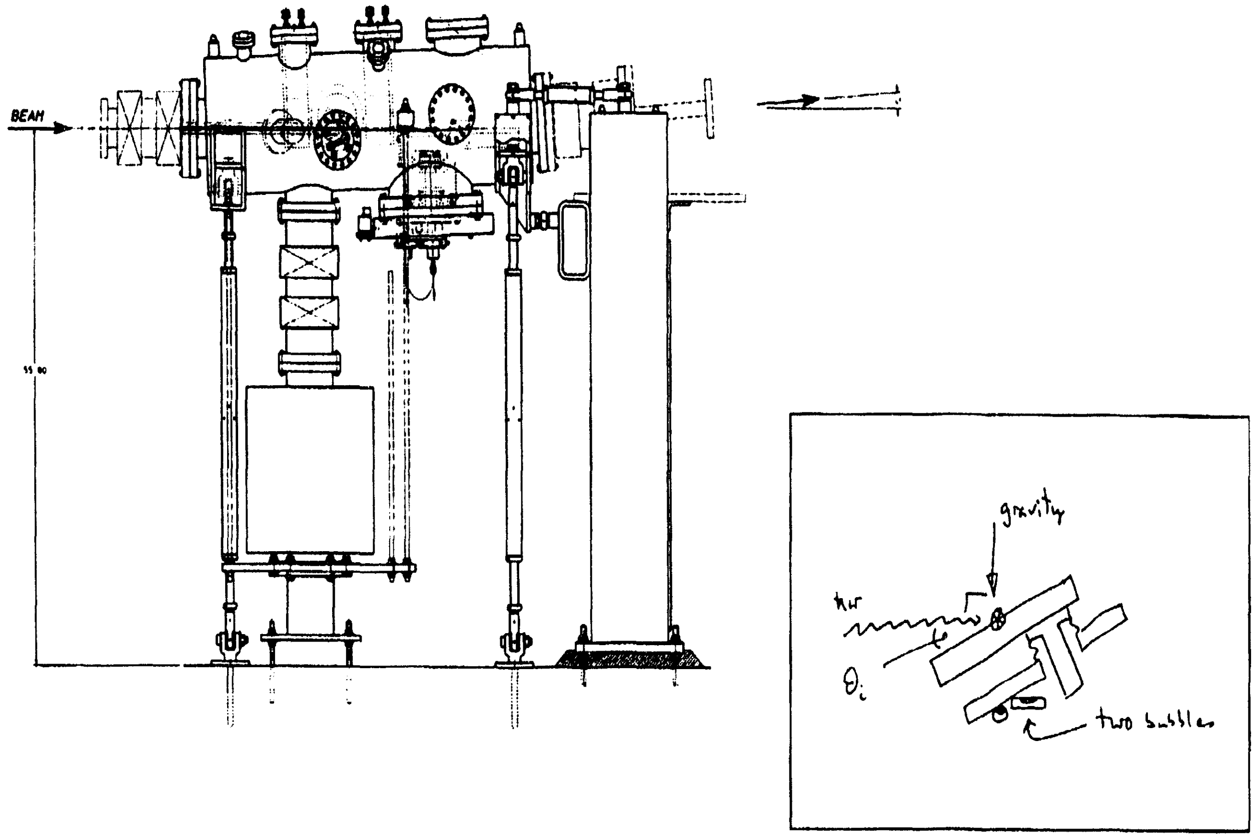

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Figure 5. Diagram of the chamber for the Beamline 7.0 vertical condensing mirror along with a sketch of the initial design concept done by Tony Warwick.

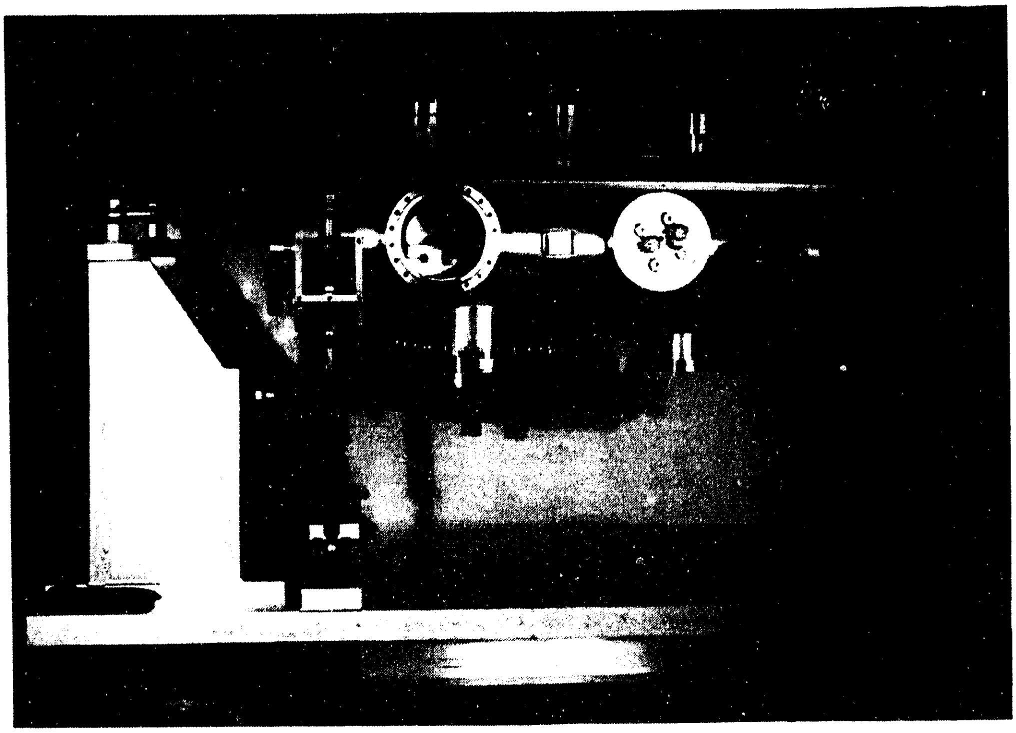

Figure 6. The vertical condensing mirror chamber ready for installation in the beamline.

The Beamline 7.0 effort has been led by Tony Warwick, with help from a large team including Dick DiGennaro (lead engineer), Gregory Andronaco (refocus mirror systems), Nord Andresen (slit design), Tony Catalano (vacuum), Carl Cork and Ken Woolfe (controls), and Al Robb (computing)—plus many more that I don't have time to mention. Many demanding technical challenges have been overcome along the way, and the quality of the finished product is a tribute to all.

As part of the initial commissioning of Beamline 7.0, we have carried out an extensive characterization of the beamline's two photon-beam position monitors (PBPMs); one inside the storage ring shielding and one outside the shield wall. The ALS-designed PBPMs provide information on the position and angle of the electron beam at the center of the undulator. Figure 7 is an early sketch of a prototype monitor by Tony Warwick and a cutaway view of the finished product. The completed instrument is shown in Figure 8. In the center of the PBPM are two copper blades that project into the path of the undulator photon beam. The photoemission of electrons from the surfaces of the blades provide signal currents to an electron-beam stabilization feedback system. The difference in the signal current readings from the two surfaces can be used to detect movement of the beam path as small as 1 μm. The blades have had to be very carefully engineered to stand the very high thermal load from the undulator and to give a high degree of position stability. We employ two types of monitor, one with one pair of vertical sensing electrodes and one with two pairs of electrodes rotated 45° for vertical and horizontal monitoring. The hope is eventually to use the signals from these monitors in an active feedback stabilization system.

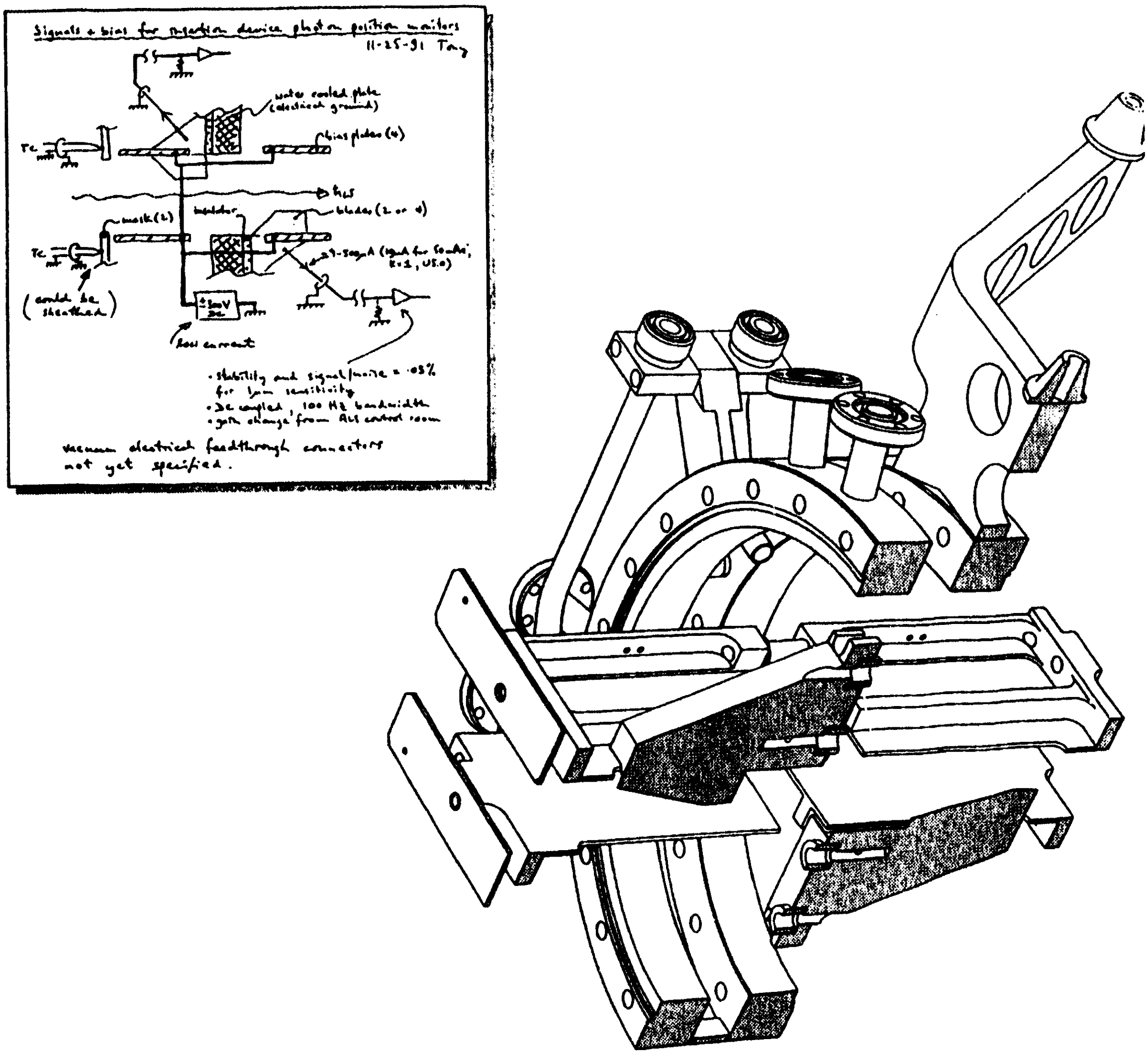

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Figure 7. ALS Scientist Tony Warwick drew the design sketch on the left for an insertion-device photon-beam position monitor in November 1991. The mechanical engineering group developed his design into the 3D CAD section.

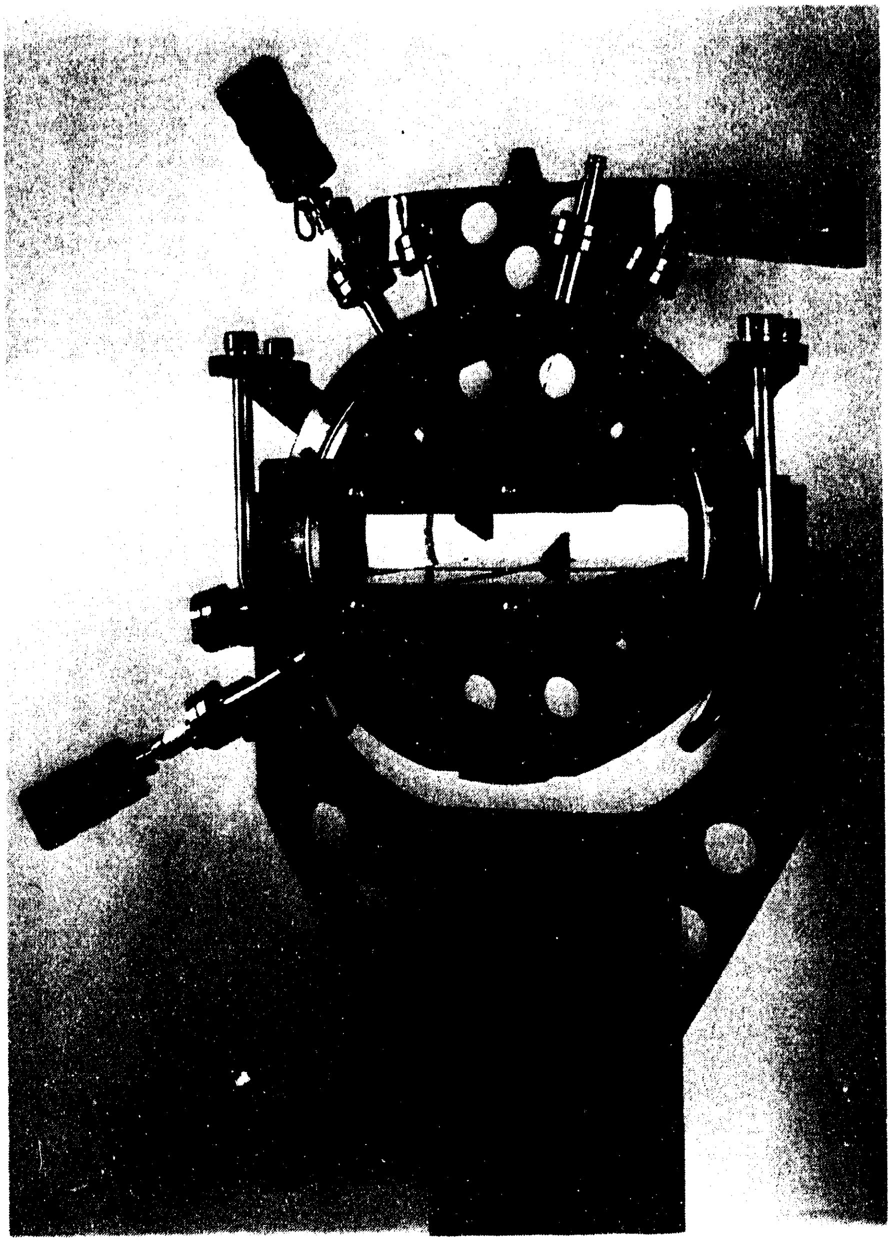

Figure 8. ALS designed photon-beam position monitor.

The good news is the monitors show the ALS photon beam to be very stable. The data in Figure 9 shows the vertical position of the beam with a calibration derived from the measured manual motion of the monitor. The short-term stability at 1 Hz is about 4 μm (1 sigma) at 10 m from the source. Clearly the beam noise is exceptionally low and reflects the high quality of the mechanical and electrical engineering on the storage ring. The long-term stability at 0.1 Hz is around 2 μm per hour at 10 m from the source. These measurements of stability show that the ALS, even without feedback, is typically 10 to 100 times more stable than the best modern storage rings. This base stability will make the implementation of a feedback system much easier than in conventional systems. The large vertical position change in the long-term stability graph is due to closure of the undulator gap from 47 mm to 23 mm and represents a motion of around 100 μm. This correlates with integrated dipole errors measured for the undulator and gives us confidence that we should be able to correct this movement with local weak corrector magnets.

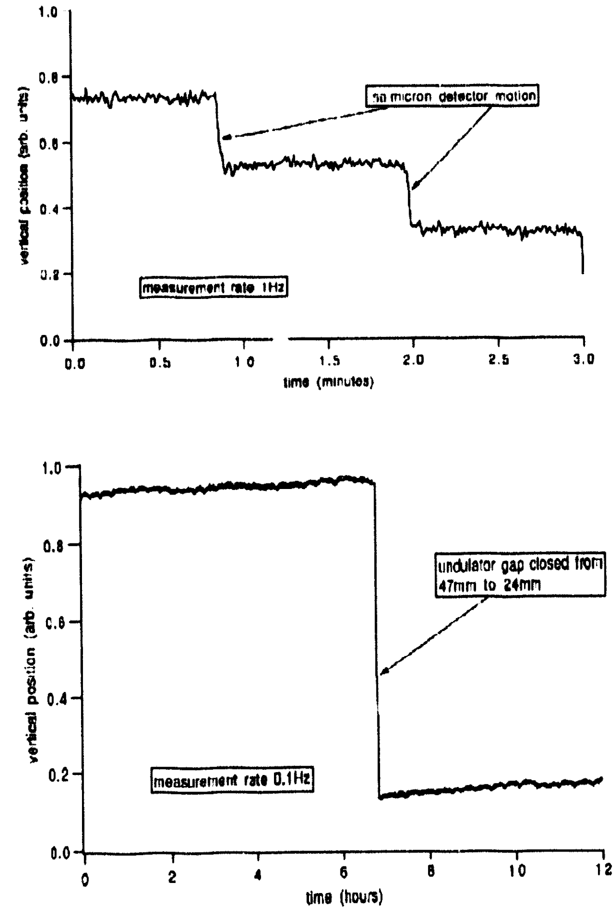

Figure 9. This data taken with the photon beam position monitors show the ALS beam to be extremely stable. Short-term stability information is on the top, long-term on the bottom. The data was taken on October 19, 1993.

Of course, one of the most important "tests of readiness" for a third-generation light source is the observation of the first undulator light. The ALS passed this test on October 18 when the Beamline 7.0 undulator became operational. To conduct spectral and positional measurements on the undulator, we installed a transmission grating spectrometer in place of the vertical mirror chamber in Beamline 7.0. Our aim is to correlate the spectral calculations that were based on the magnetic field measurements made on the undulator structure with the measured spectral and angular characteristics. The calculations show that the measured magnetic errors should reduce the brilliance of the fifth harmonic to around 75% of the zero error case for the minimum magnetic gap of 14 mm. The spectral calculations were done by Chun Z. Wang and the undulator measurements were carried out by Steve Marks and other members of the Insertion Device Group led by Egon Hoyer.

Figure 10 is a diagram of the transmission grating spectrometer (TGS) system. The TGS consists of a grazing incidence mirror which focuses undulator light through a transmission grating onto a movable slitted detector which can be rotated to select different wavelengths. The system is designed to have a resolution better than the width of the fifth harmonic at all wavelengths. The mirror reflectivity, grating transmission, and detector response are have all been calibrated so that we can extract reliable intensity information. Figure 11 shows the TGS installed in the beamline with part of the team responsible for its design and construction. Again, the system was constructed in record time and worked immediately. The team of Bill Gath, Jason Acre, Al Robb, John Chin and Dimitri Mossessian led by Phil Heimann have done a remarkable job in getting useful data out of the system in record time.

- 2000 and 5000 1/mm gratings
- 29:1 vertical demagnification
- wavelength and x,y scanning

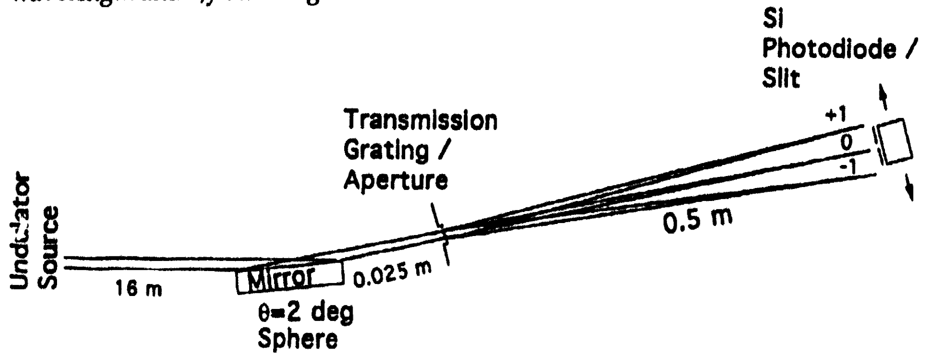

Figure 10. The transmission grating spectrometer (TGS) installed in Beamline 7.0 is used to disperse and focus radiation from the undulator onto a slit and detector. By moving the slit, the analyzed wavelength can be changed to produce a spectral scan.

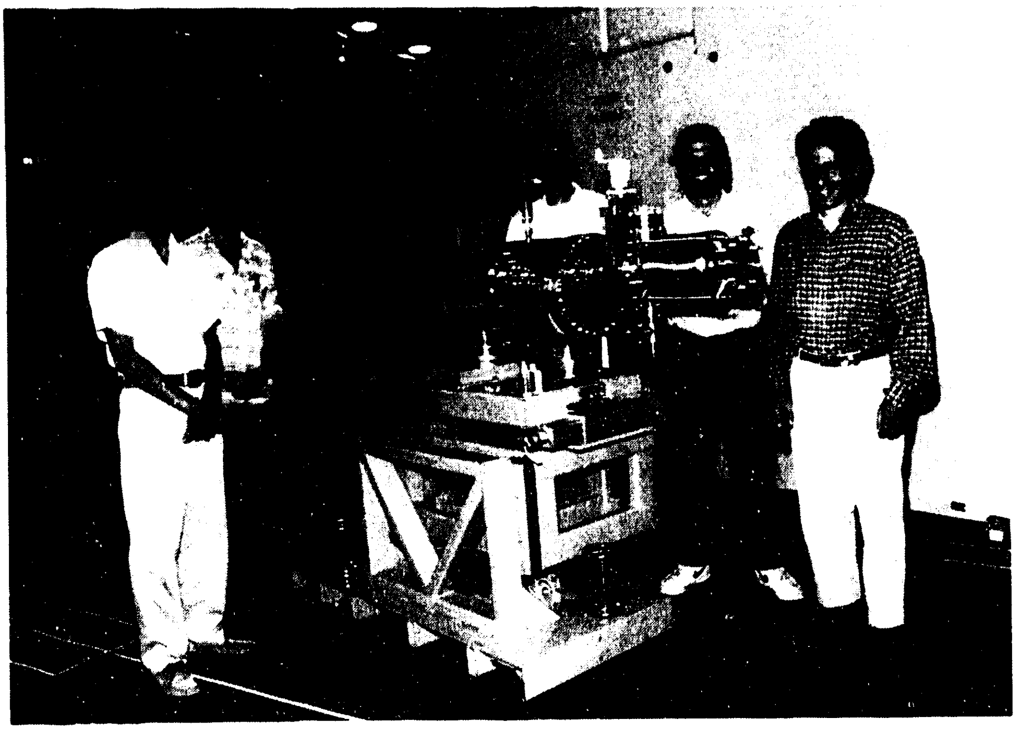

Figure 11. Members of the ALS Experimental Group responsible for the design and calibration of the TGS include (from left) John Chin, Bill Gath, Terence Akins, Al Robb, Jason Acre, Phil Heimann and Dimitri Mossessian (not pictured).

Figure 12 is a graph of a TGS scan at an undulator gap of 47 mm. Starting from the left, the peaks correspond to the zero order of the grating, a very small 4th harmonic, the third harmonic, the second harmonic, the third harmonic in the second diffraction order of the grating, and the first harmonic. This is operating at a deflection parameter K of around 0.5 and therefore shows strong first order content. The data in Figure 13 was taken with the undulator gap set to 23 mm and shows harmonics up to the 15th and many diffraction orders of the grating. The first order is suppressed as the first harmonic energy (126 eV) is just above the Si 2p absorption (99.7 eV), and there is large absorption in the oxide dead layer on the surface of the diode. We have compared the results from the TGS to the theoretical predictions based on the measured magnetic data and so far our preliminary data shows very good agreement, indicating a highly optimized undulator structure. This result is a testament to the quality of work of Ross Schlueter and the Insertion Device Group led by Egon Hoyer including Steve Marks, Dave Plate, Dave Humphries, John Chin, Greg Portman.

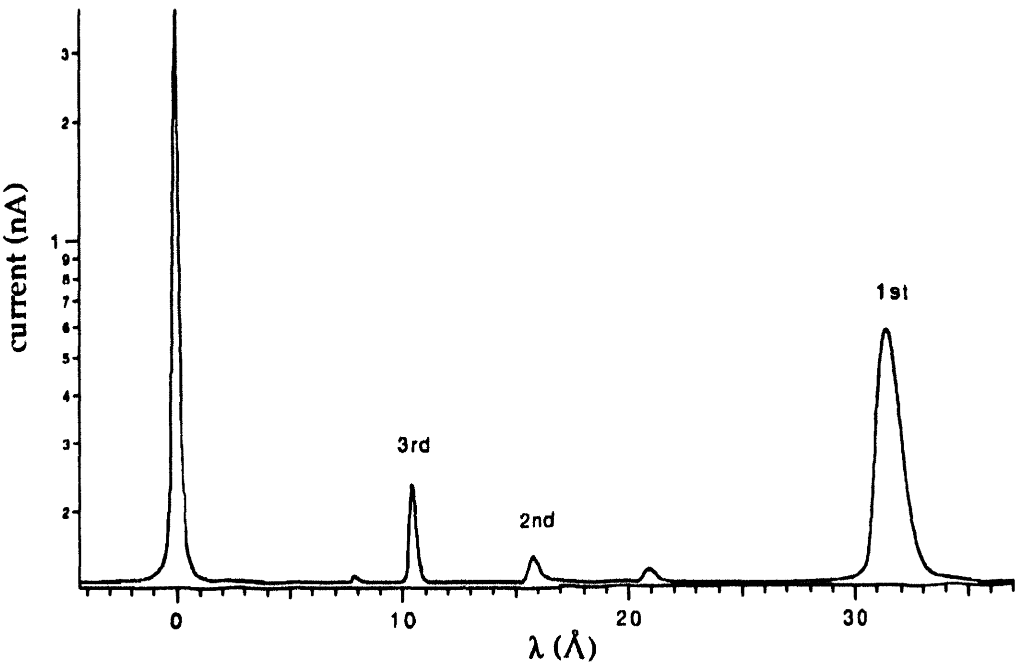

Figure 12. TGS scan of the 5-cm-period undulator installed in sector 7 of the storage ring; the undulator gap is set at 47 mm. The data was taken on October 19, 1993.

Work is continuing for the next month using the transmission grating spectrometer to fully characterize the undulator output, and we hope to gain a much deeper understanding of the role of errors by experimenting with the undulator and introducing artificial misalignments such as taper and roll. The instrument will also be used on Beamline 9.0 after the spring shutdown to test the U8 undulator.

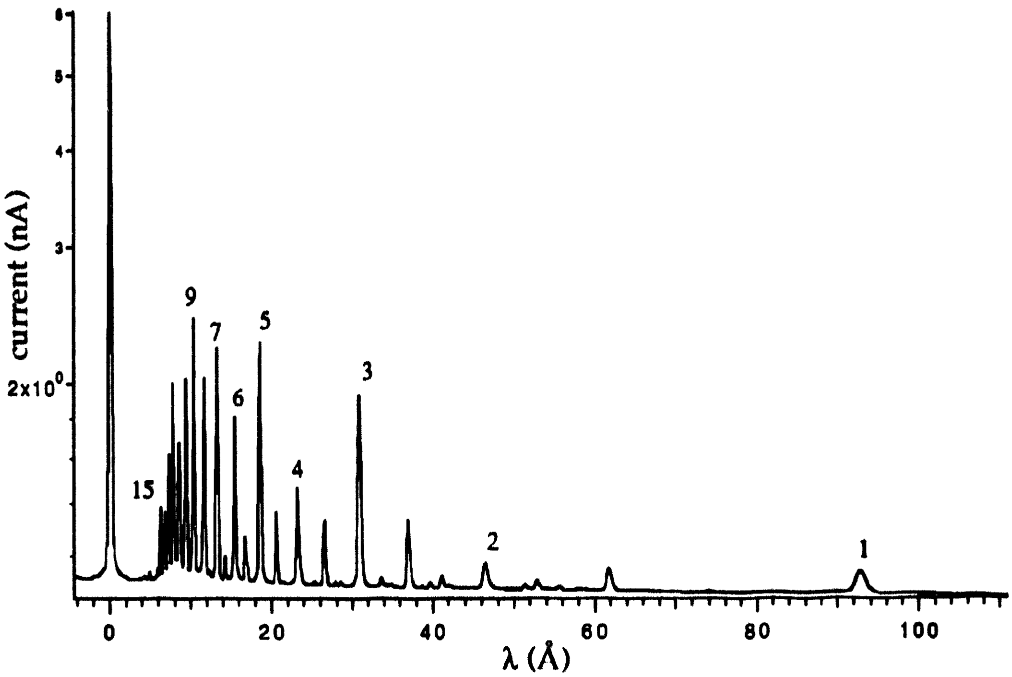

Figure 13. TGS scan with a 23 mm gap in the undulator for Beamline 7.0. The data was taken on October 19, 1993.

Let me conclude my discussion of Beamlines 3.1 and 7.0 by pointing out that the data and results I've shown in this talk have all been taken within 2 days of turning the beamlines on for the first time. The respective teams and team leaders for the 7.0 beamline (Tony Warwick), the transmission grating spectrometer (Phil Heimann), and the diagnostic beamline (Ed Melczer), all worked extremely hard over the past few months to get data for the user meeting and are to be congratulated on achieving this excellent result.

Next I would like to give a brief overview of three new projects the Experimental Systems Group is involved with. The first is an elliptical wiggler insertion device to generate circularly polarized light which is planned for sector 11 of the storage ring. The mechanical design of the magnetic structure is already well advanced and is a novel combination of a standard permanent-magnet hybrid structure for the vertical field and an electromagnet array for the horizontal field. The intention is to switch the polarity of the horizontal field at a frequency of up to 1 Hz. The device works by aligning the light of the same helicity from adjacent poles by deflecting the vertical orbit in opposite directions between poles. This deflection is symmetric and hence only one helicity is propagated along the central axis of the device. To change the helicity, the horizontal field polarity is reversed. We held a one day workshop on this project in April from which the design of the magnetic system and optical system have been developed. Extensive work has been carried out by Chun Z. Wang to predict and optimize the optical properties of the source. We now have a complete understanding of the method of optimization and are currently using this in the design of a high-acceptance monochromator for the system.

In collaboration with a research team led by Professor Yuan Lee of the University of California at Berkeley, we are currently designing and building a branchline for the 8-cm-period undulator beamline (9.0) for chemical dynamics. The branchline has two primary end stations; one using white undulator light and the other using monochromatized radiation. The monochromator is an off-plane eagle instrument and will be capable of resolutions in the VUV of up to 2×10^5. The extreme mechanical stability required by this system will be a challenge both optically and mechanically. When completed, it will be the first of its kind in the world and will provide unprecedented flux at very high resolution. The experimental end stations will also be complex system using pump-and-probe techniques with high power lasers and crossed molecular beams.

A third new project is a beamline for protein crystallography. We have developed a beamline plan, a design for the multipole wiggler source, and have investigated the possibility of industrial funding. So far we have interest in the project from several companies who would like local access to a facility for rapid and reliable turnaround in diffraction measurements. A further requirement is for a well developed biological support infrastructure and this will be funded under a separate initiative over a period of three years. The emphasis in our proposal is for highly automated operation with the maximum convenience for the user. The support laboratories will offer a comprehensive computing system so that users can do their basic data reduction on site, as well as the normal preparation and analysis laboratories.

Finally, I would like to return to the graphs I showed of the first undulator output from Beamline 7.0 (Figures 12 and 13). We should remember that this result is due to the contributions of many, but in particular to the inspired invention of the permanent magnet undulator by Klaus Halbach, and to the implementation of that idea by Egon Hoyer. In this year of Klaus' retirement, I would like to suggest that we start an annual prize for outstanding instrumentation in the field of synchrotron radiation at the ALS, called the Halbach Prize. Klaus will select the winner in coming years, but I think it is appropriate for the prize in its first year to be awarded to Klaus and Egon for their outstanding contributions to the development of modern undulator technology (Figure 14).

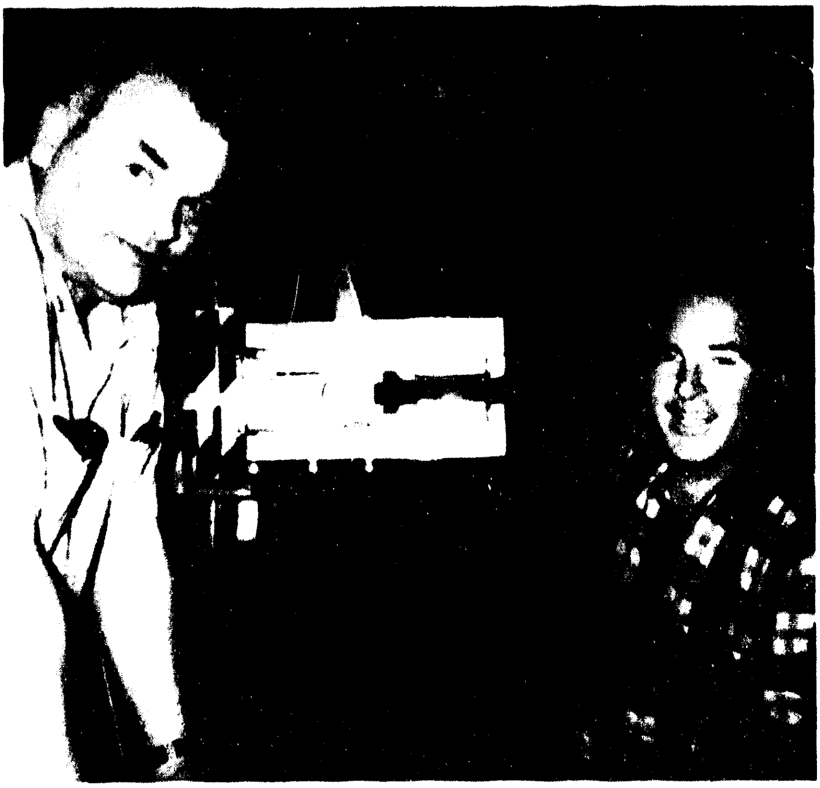

Figure 14. Klaus Halbach and Egon Hoyer with the first undulator they designed and built based on Halbach's idea of using of permanent magnets in insertion devices. The undulator was installed in the SPEAR storage ring at Stanford in 1980.

ALS User Program

A. S. Schlachter

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Advanced Light Source
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My presentation will give an overview of the ALS user program, including why you might want to become a user of the ALS and what you can expect when you get here.

I would like to start by describing some of the features that distinguish the ALS from other facilities. Light from the ALS possesses special characteristics that make it a research tool of great versatility:

- Very high brightness
- Fast pulse (35 ps)
- Tunability over a wide range (far ultraviolet and soft x ray)
- Partial coherence
- Linear or circular polarization.

Of these, the one that sets us apart from other synchrotron sources in our unusually high brightness. "High brightness sounds good, but what are you going to do with it?" you might ask. The answer is—there are two things you can do with it. The first one is achieving high spatial resolution, the ability to focus the beam to a very small spot. The smaller the focal spot, the smaller the object that can be distinguished from its surroundings. The second is, it gives you high spectral resolution with high flux. By narrowing the slits at the entrance and exit of a monochromator, you can select a very narrow range of wavelengths from a beam of synchrotron radiation, and in this way achieve very high spectral resolution.

Let me give an illustration of why high spatial and spectral resolution are important. Figure 1 shows some spectral measurements done by Phil Heimann and Zahid Hussain. The measurements on the graph on the lower-right have a resolution of 1500 and all you see is a big blob. So if your instrument has a resolution of 1500, you might as well go home because you haven't learned anything. It isn't until you get to a resolution of 5000 (top-center) that you see the full structure of nitrogen's vibrational levels. Also notice that, in this case, going to a resolution of 6700 doesn't help you because you've now exceeded the natural linewidth. There are other examples however, such as doubly excited levels of helium, where you want to go way beyond this.

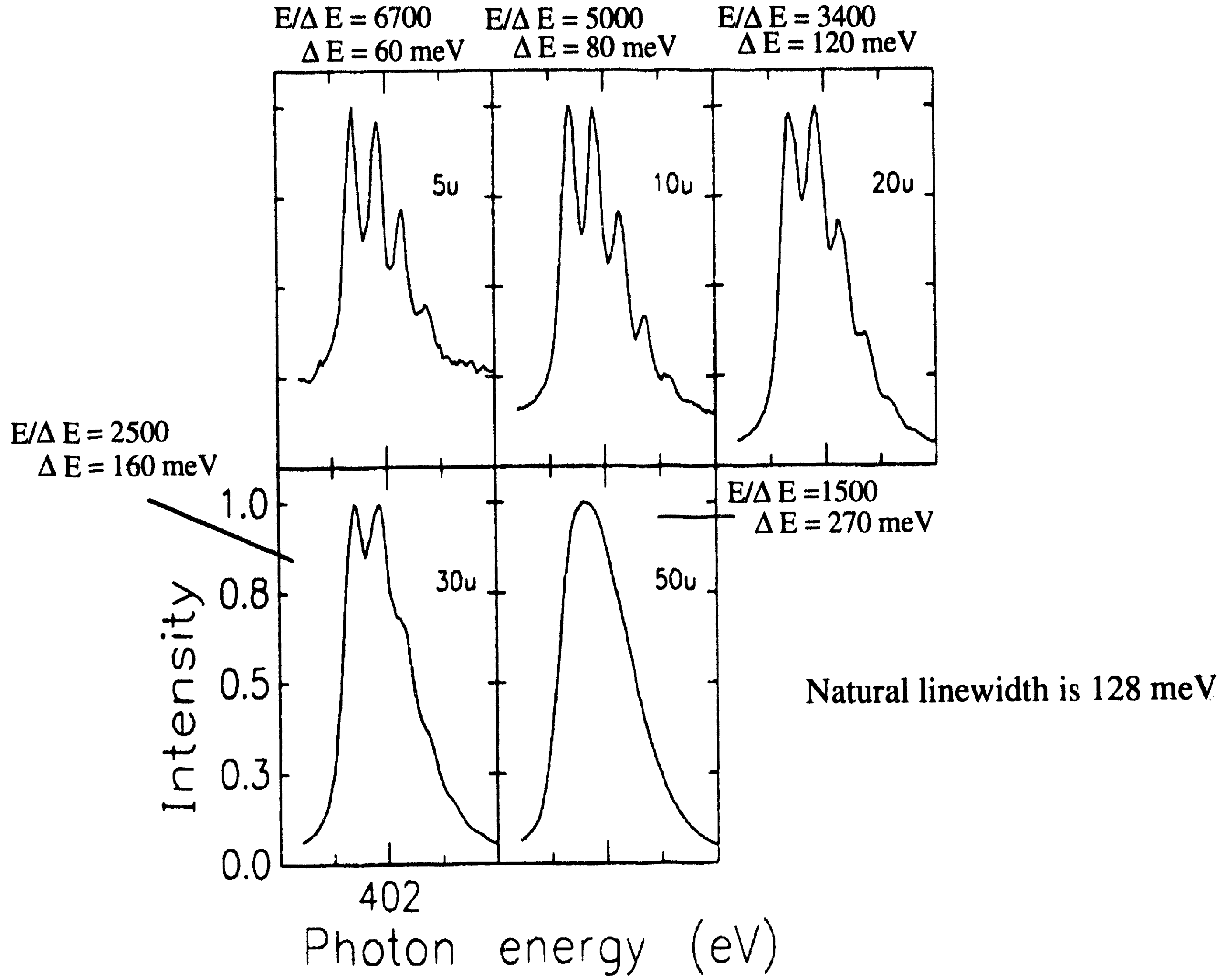

Figure 1. Spectra of the nitrogen 1s →π transition.*

Another example of the type of research that can take advantage of the high-brightness of ALS light can be seen in Figure 2. What you are looking at is the magnetic bits on a storage disk with dimensions of 10 x 10 μm, 10 x 2 μm, and 10 x 1 μm. The image was obtained by subtracting two images recorded with right circularly polarized synchrotron light tuned to the cobalt L_3 and L_2 x-ray absorption edges. The contrast comes about from the orientation of magnetic spins. This work was done by Jo Stöhr and the IBM group at SSRL last year.

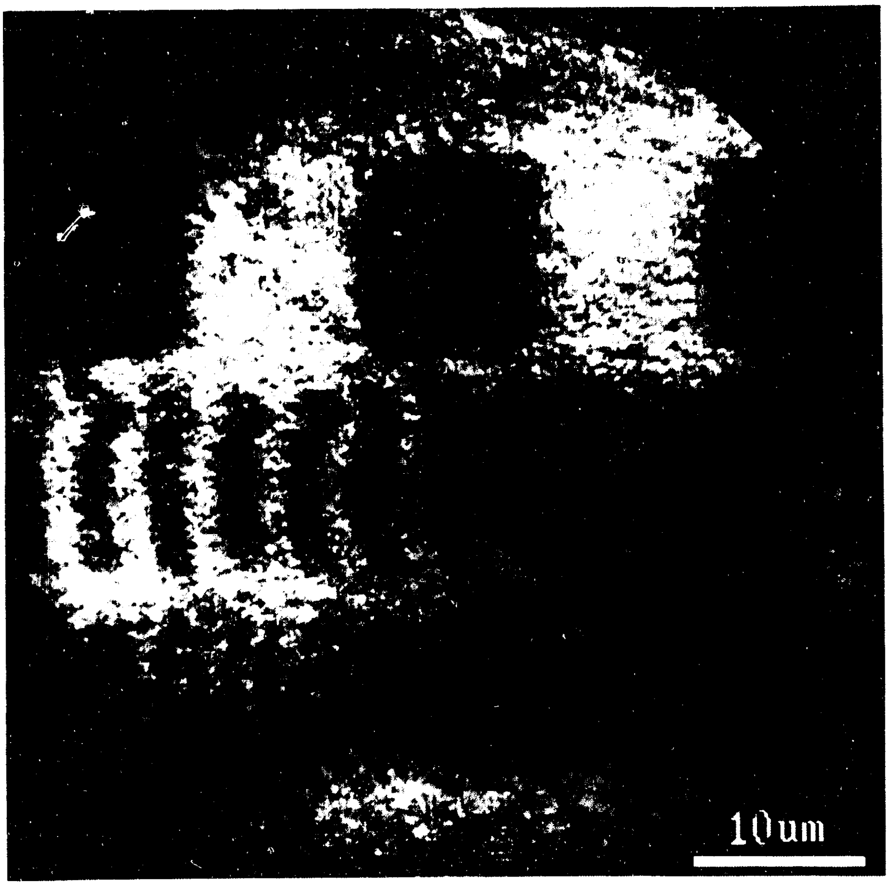

Figure 2. Image of data bits on a magnetic storage disk obtained by using circularly polarized light.

Now that we have established why you might want to come here, let's see how you can join this group. There are three ways to become an ALS user:

- Join an existing participating research team (PRT)
- Form your own PRT
- Submit a proposal as an independent investigator.

To join an existing PRT, you should contact one of its members as it is up to them whether or not you join the group. The second option, starting your own PRT, typically requires having enough resources to build and pay for an insertion device or a beamline. The third way is to submit a proposal as an independent investigator, just like at Brookhaven and other synchrotron sources. A formal ALS proposal process will be initiated sometime in 1994. In the meantime, if you have an idea that can't wait, please send us a Letter of Interest now and we'll try to get you on the experimental floor.

The beamlines and areas of research planned for the next few years are summarized in Figures 3 and 4. As you can see, the ALS scientific program encompasses a broad range of scientific disciplines. And the ALS has several ongoing efforts to develop new research opportunities. These include focusing interest on new areas through workshops, working with industry on commercially promising applications, and investigating additional ways of providing analytical or other services to users.

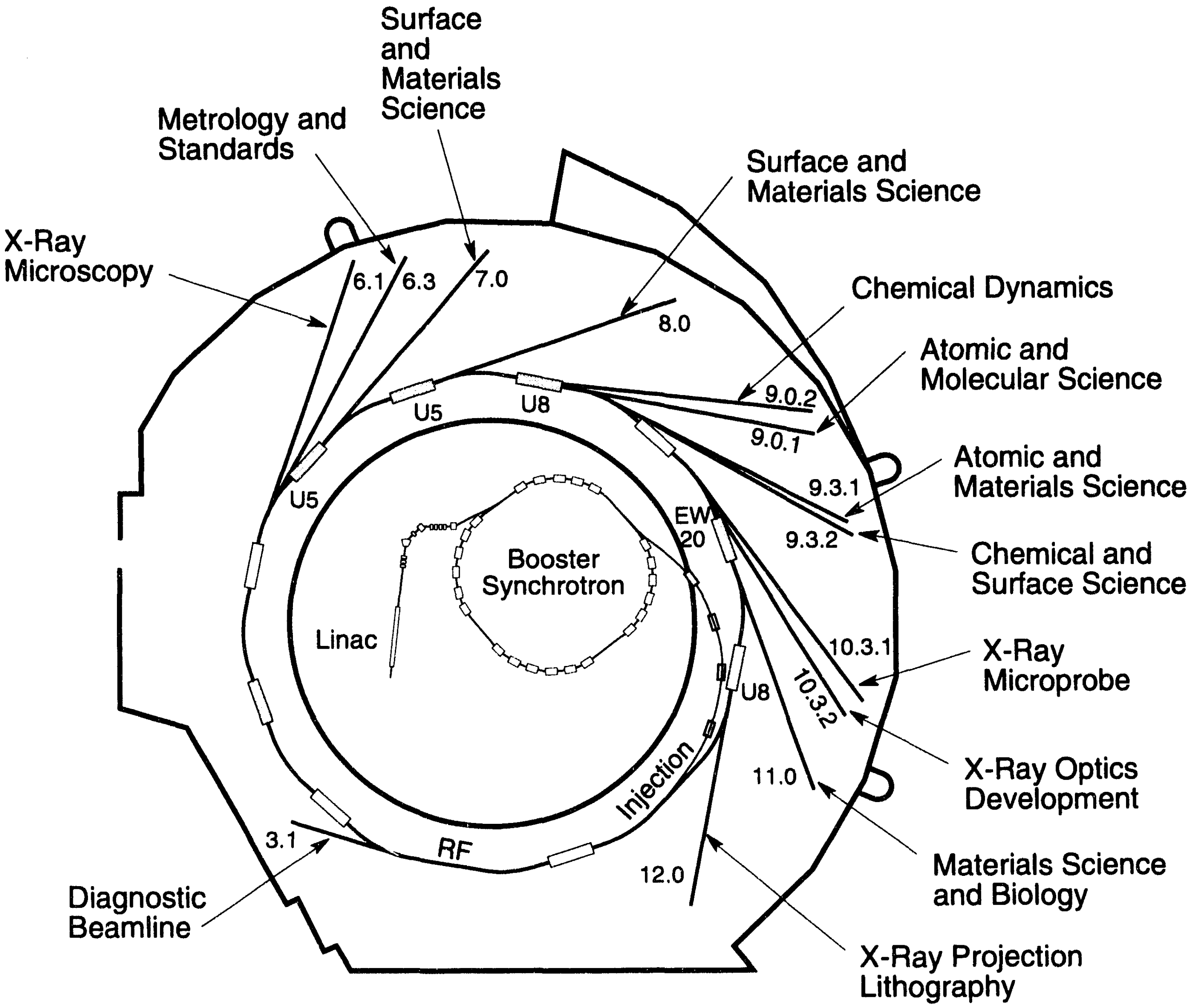

Figure 3. Diagram of the ALS floor showing the beamlines planned for construction through 1995.

Beamline	Source	Research	Energy Range	Avail.
3.1	Bend magnet	Diagnostic beamline	200 eV	Now
6.1	Bend magnet	High-resolution zone-plate microscopy	250–600 eV	1994
6.3	Bend magnet	Metrology and standards	50–4000 eV	1994
7.0	U5 undulator	Surfaces and materials, spectromicroscopy	70–1200 eV	Now
8.0	U5 undulator	Surfaces and materials	70–1200 eV	Now
9.0.1	U8 undulator	Atomic physics and chemistry	20–300 eV	1994
9.0.2	U8 undulator	Chemical dynamics	5–30 eV	1994/95
9.3.1	Bend magnet	Atomic and materials science (double crystal)	700 eV–6 keV	1994
9.3.2	Bend magnet	Chemical and materials science	30–1500 eV	Now
10.3	Bend magnet	Materials science and advanced microprobe instrumentation	3–12 keV	Now
11.0	EW20 elliptical wiggler	Materials science and biology, magnetic materials	50 eV–10 keV	1995
12.0	U8 undulator	X-ray projection lithography, optics development	60-320 eV	1995

Figure 4. The beamlines and areas of research for 1993–1995 operations.

Now I'd like to discuss the logistics involved with being a user at the ALS. Let me begin by saying that both the Laboratory and the ALS recognize the importance of creating an efficient check-in process and working environment for users, and are working together to make all aspects of conducting research here as convenient as possible.

The first stop for users when they come to work at the ALS is the new LBL Reception Center, located in Building 65 near the LBL shuttle-bus terminal (Figure 5). Here you complete their registration forms, obtain an identification badge and parking permit, and receive the required safety training. The Reception Center can also provide information on hotel and housing accommodation.

CURRENTS Friday, March 26, 1993

RECEPTION CENTER OPENS

Receptionist Rory Perry holds down the fort while (left to right) Reception Center Manager Fred Lothrop shows off the new center, in Bldg. 65, to Associate Lab Director for Administration Rod Fleischman and Lab Director Charles Shank. *Photo by Steve Adams*

Figure 5. First stop for ALS users is the LBL Reception Center where they will get their identification badge and take the required safety training.

During their stay, users are assisted with the logistics of conducting research by operations coordinators under the supervision of our user support leader, Ray Thatcher. During operations, at least one operations coordinator is always available on the experimental floor as a first contact for questions or problems and to ensure compliance with safety regulations. The operations coordinators inspect and enable beamlines, check that users have the appropriate training for the beamline and experimental equipment, and make sure hazardous materials are handled properly. In addition, they can help users gain access to LBL and ALS crafts and trades such as survey and alignment, crane operators, and electronic and mechanical technicians. Several of the user service areas are now complete including a wet lab, a clean assembly area, stockroom, and a user machine shop.

The ALS is here to serve the needs of the user community and spends considerable effort to keep in touch with what those needs are. The Users Executive Committee represents users to ALS management and gives valuable feedback and advice. The ALS publishes a variety of newsletters and brochures to keep you informed about recent progress, research opportunities, and beamline status; and sponsors a variety of meetings and workshops to explore new scientific opportunities for synchrotron light sources. This year we held an informal workshop in April to discuss the production and user of elliptically polarized radiation at the ALS, and one in June on soft x-ray interferometry.

In conclusion, it is my goal as head of the user liaison group to establish the best possible environment for research at the ALS. I look forward to working with you, members of the ALS user community, to make your visit to our facility an enjoyable and productive one.

The Fluorescent X-Ray Microprobe Beamline At The ALS

A.C. Thompson, P.J. Batson, K.L. Chapman, R.E. Tackaberry and J.H. Underwood

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Introduction

A fluorescent x-ray microprobe has been built by the Center for X-Ray Optics and the Materials Science Division of LBL. It uses a bending magnet port on the new Advanced Light Source (ALS) at the Lawrence Berkeley Laboratory. The ALS provides an excellent source of x rays for a hard x-ray microprobe because it has high spectral brightness (flux per unit area of the source, per unit solid angle of the radiation cone, and per unit bandwidth). The small emittance of the x-ray beam allows the full beam to be demagnified with a pair of mirrors to produce a small spot size. The mirrors are arranged in a Kirkpatrick-Baez configuration and they are coated with a W/C multilayer which enables them to focus and monochromate the white radiation beam from an ALS bending magnet port.

Elemental analysis using a synchrotron-based fluorescent x-ray microprobe provides high elemental sensitivity, spatial resolution approaching 1 µm2 and the ability to examine samples in a variety of environments. Elements can be quantitatively and non destructively detected by means of the characteristic fluorescent x rays emitted by the irradiated sample. The fluorescent x rays are detected in a Si(Li) detector which measures simultaneously measures the Ka fluorescence lines of the elements K through Zn. The energy of the emitted radiation identifies the element and the intensity is a measure of the quantity. Additional detection sensitivity for particular elements can be gained by tuning the incident x-ray energy (from 3 to 10 keV) to avoid excitation of the K or L lines of interfering elements.

Beamline Design

The beamline is installed on bending magnet port 10.3 of the ALS. It has two independent branches that will each provide a 2 mrad-wide white radiation beam. One branch line is dedicated to routine x-ray microprobe experiment and the other branch will be used to test new experimental systems. Only one branch line is fully installed at this time. Figure 1 shows the general design of the microprobe optical elements and Figure 2 show a layout of the beam line.

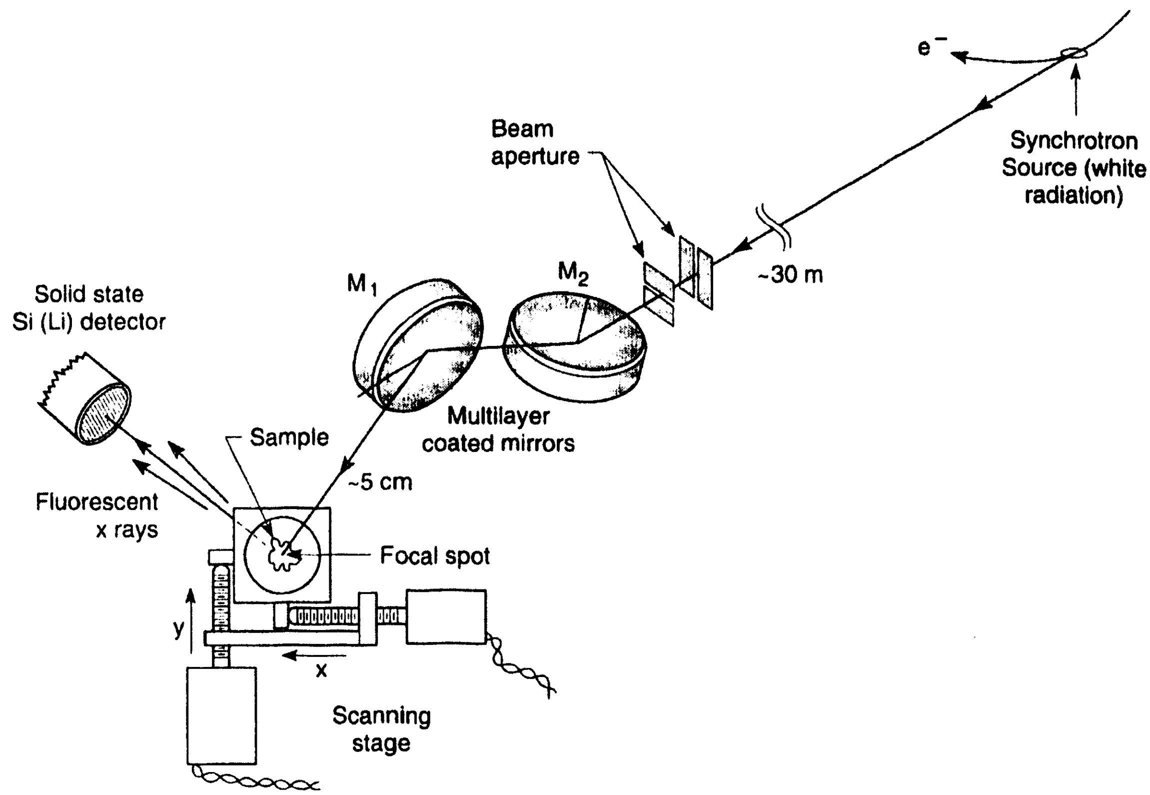

Figure 1. Schematic view of the fluorescent microprobe focusing mirrors and scanning stage.

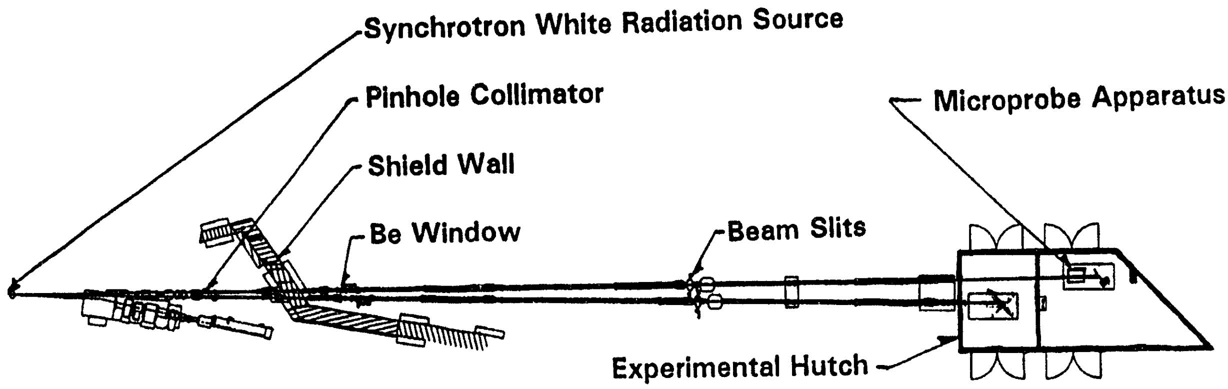

Figure 2. Top view of the CXRO/MSD microprobe beamline at the ALS.

Figure 3 shows the front part of the beam line outside the shield wall. Figure 4 shows the end of the beam line the two experimental areas. Each area is large to accommodate a wide variety of experiments. They are radiation shielded so that the white radiation beam can safely enter the hutch and both branches can operate independently.

Inside the first hutch is a large, computer controlled table on which the experimental equipment is mounted. The microprobe experiment consists of horizontal and vertical slits followed by an ion chamber, two multilayer mirrors positioned at 90 degrees with respect to each other, a sample scanning stage and a rear ion chamber. A Si(Li) detector measures the fluorescent x rays from the sample and an optical microscope is mounted so that it views the front side of the sample.

Figure 3. Front part of the beamline with Matt Fryer at the computer terminal.

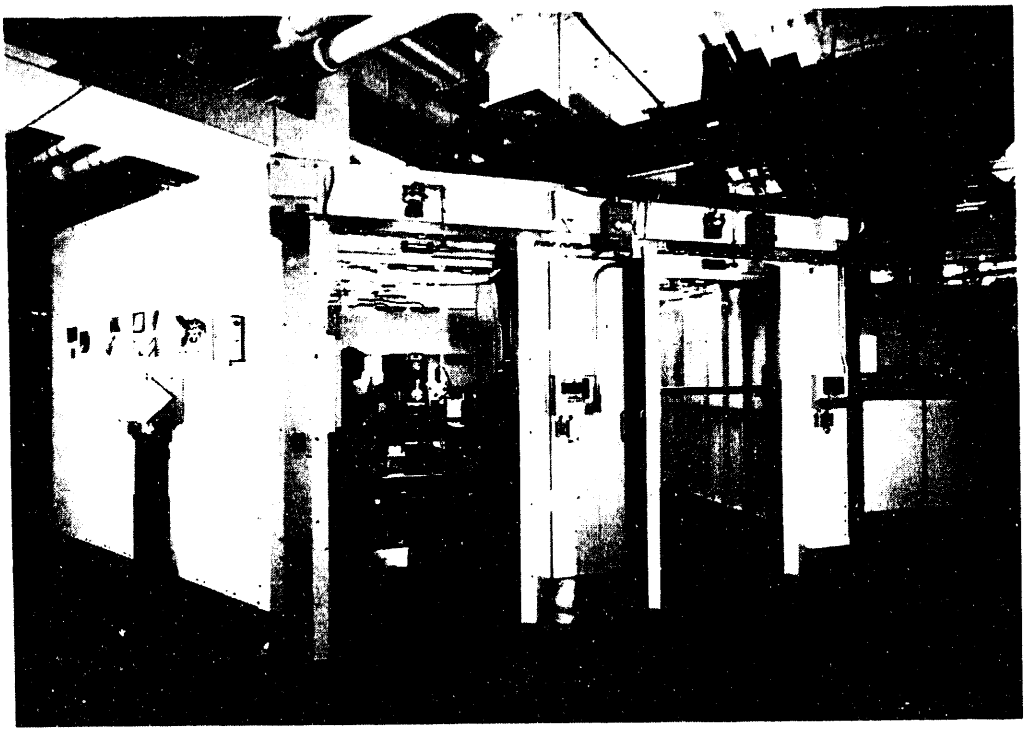

Figure 4. Rear part of beamline showing the two independent experimental areas.

The microprobe beam line was the first operating beam line at the ALS. On October 4 at 11:34 we saw the first "light" from the ALS. An orange phosphor was placed just inside the hutch so that the incident white beam from the ALS would strike it. The phosphor was viewed by a TV camera. Figure 5 shows the bright orange image that was seen that night by many of the participating scientists and technicians that built the beam line. Figure 6 shows many of the CXRO/MSD personnel who participated in the design, building and commissioning of the beam line.

In the few days between the first light from the ALS and the ALS Users' meeting we were able to successfully focus the white radiation beam down to a spot size of 2 μm x 3 μm with a pair of multilayer coated spherical mirror.

Conclusions

The excellent beam emittance of the ALS allows the full beam to be demagnified to a very small spot size. A beam spot size of 2 μm x 3 μm has already been produced with a bandwidth of 1 keV at 10 keV. When the microprobe beam line at the ALS begins full operation in 1994 it will provide the ability to simultaneously measure femtogram amounts of elements from K to Zn. In 1994 we plan to install elliptically curved multilayer mirrors instead of the current spherical mirrors. This will enable us to achieve a spot size of less than 1 μm^2.

An example of an important application of the x-ray microprobe is the spatial distribution of trace element within ceramic samples. The structural characteristics of ceramics are often determined by the distribution of different particles within the ceramic. The x-ray microprobe will be useful for the characterization of particle size and spatial distribution of different elements. These characteristics will then be related to the structural properties of the different samples. Particular areas that will be studied include cleavage in bulk ceramics and ceramic composites, crack growth due to stress or fatigue, and fracture at the ceramic/metal interface in metal-matrix composites.

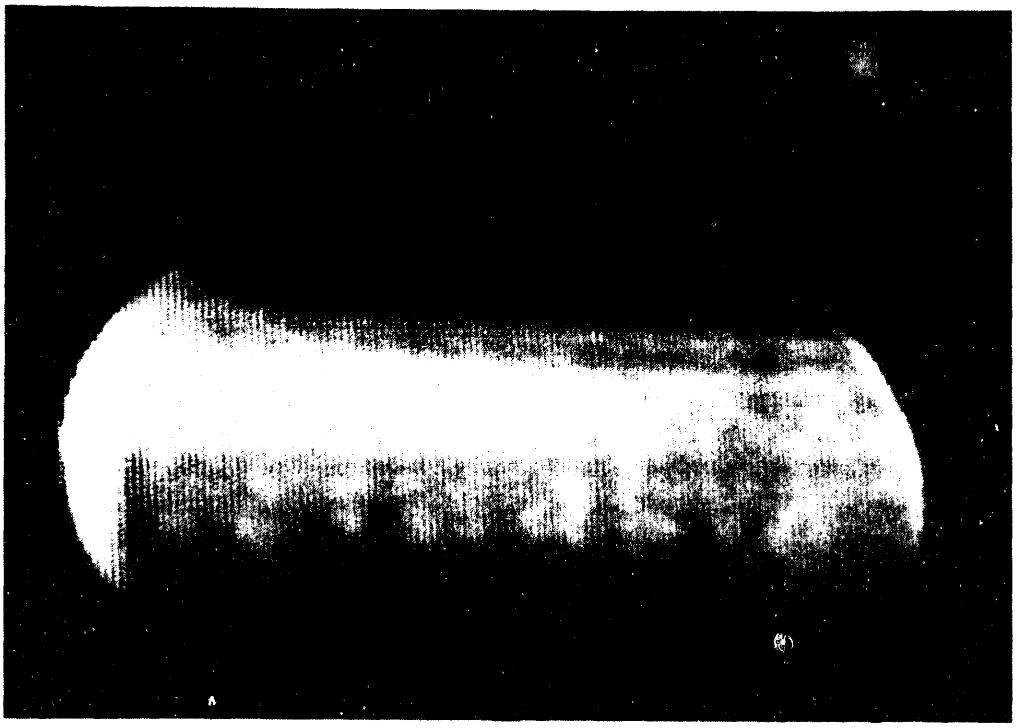

Figure 5. Photograph of the "first light" out of the ALS that was achieved on October 4, 1993.

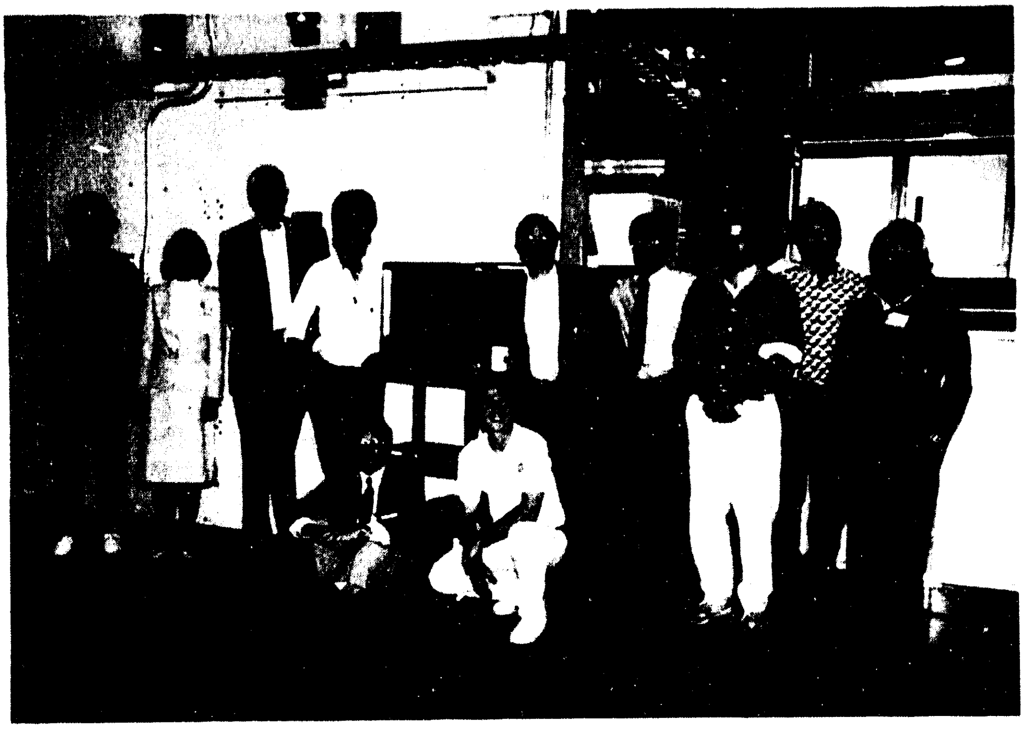

Figure 6. Photograph of members of CXRO/MSD who helped build the microprobe beamline. From left to right P. Batson, K. Chapman, A. Thompson, D. Kemp, D. Chemla, R. Tackaberry, J. Underwood, P. Ross, S. Klingler, T. Swain, M. Fryer, and J. Galvin.

The Early Days of X-Ray Optics: New Light — New Knowledge

Introduction

I am very pleased to be here with you this evening because it gives me the opportunity to pay homage to Paul Kirkpatrick, one of the important pioneers in x-ray optics. In the early 1940's, I benefited in many ways from being his student. I also discovered that we shared a sense of humor as well as a love of teaching and of music.

The invitation that Dr. Alfred Schlachter sent to me read: "Because there will be non-physicists at the dinner, we would appreciate that your talk be suitable for a lay audience." I think that if I put emphasis on anecdotes that center around Professor Kirkpatrick, or PK as he was fondly known, I'm sure I will be able to do that.

I shared with PK a philosophy of education based upon the idea that the two most important functions of teaching are to inform and to motivate but that of the two, motivation is the more important. And, if in the process you can also entertain, so much the better.

PK had a flair for the dramatic and the humorous. He had grown a beard which he sported because he liked it. But his wife Mary Rose disliked it and kept urging him to shave it off. One morning he came to breakfast with half of his beard shaved off. His comment was "I compromised."

We both enjoyed setting up lecture-room demonstrations to illustrate topics in physics. In the introductory physics course, he would darken the room and show how x rays from a medical x-ray tube produced a visible image on a large fluorescent screen of an object that intercepts the beam. He would ask a woman student to lend him her purse—they carried such things in the 40s—so that we could all see what was inside of it by casting its x-ray shadow on the screen.

Actually, he had prepared in advance another purse into which he had placed a revolver and, in the darkened classroom, he substituted this purse for the one that had been given to him. To everyone's amazement and glee and the purse owner's chagrin, the shadow of the gun could be seen inside the purse. I realized at once that I was going to enjoy working with this man.

The Professors Return—Research Begins Again

The early days of x-ray optics at Stanford were also the early days of nuclear magnetic resonance under Felix Bloch who later won a Nobel Prize and of the linear electron accelerator (now called SLAC) under Bill Hansen. In the mid-forties the physics professors were coming home from building bombs at Los Alamos or perfecting radar in Cambridge, Massachusetts.

I had come to Stanford in the 40s to teach a physics course in the Army Specialized Training Program (ASTP). I stayed on to continue teaching, studying for a Ph.D., and doing research with PK. I remember getting paid 35 cents an hour for doing research and scavenging through the junk pile in the physics machine shop for materials to build our equipment. There was hardly any money for research but there was a lot of pent-up energy on the part of investigators who were anxious to get back to the research they had put off for years.

Kirkpatrick, who had stayed on at Stanford as acting head of the physics department, had devoted his full time during the war years to administering the teaching of physics to a large body of students who had enrolled in the ASTP program. As soon as the war was over, however, he moved quickly to develop his idea for an x-ray microscope.

I had the good fortune of building the fist x-ray microscope as a graduate student under PK. The title of my dissertation was *Principles of X-ray Optics and the Development of a Single Stage X-Ray Microscope.* To the best of my knowledge, this was the first use of the term x-ray optics.

X rays had already been reflected as grazing incidence from flat mirrors but the books still said it was impossible to focus x rays. Kirkpatrick and others did focus them in several ways by reflection at grazing incidence from curved mirrors, but Kirkpatrick was the first to show how two curved mirrors can focus x-ray radiation from a point source to a point image. One mirror squeezes x rays from the point source down to a line, but if the radiation is allowed to hit a second mirror at right angles to the first, the line is squeezed down to a point. An extended object is focused into an extended x-ray image whose magnification depends only on geometric factors.

Kirkpatrick was one illustrating this phenomenon at a physics colloquium at Stanford in the 40s by using visible light and cylindrical lenses instead of mirrors. The object was an illuminated rectangular wire mesh. The image it produced on a projection screen using a single cylindrical lens consisted of a set of parallel lines. Kirkpatrick then predicted that, when he introduced a second cylindrical lens into the beam at right angles to the first, the combination of two cylindrical lenses would behave like a single convergent spherical lens. There was a flurry of disbelief among the members of the audience, which included at least one future Nobel Prize winner. Kirkpatrick paused, to heighten the interest of the audience. When he introduced the second cylindrical lens into the beam, a clear enlarged image of the entire rectangular mesh appeared on the projection screen. The audience applauded.

New Light, New Knowledge

I used to do a classroom demonstration with what was called black light. It was actually an electric light bulb with a dark glass envelope which did not let much visible light through but it did put out invisible near-ultraviolet radiation. If you turned the room lights out and shone the black light on a student's teeth and nails, you would see them fluoresce. They lit up under the ultraviolet.

I took it home one night because I was having some students over for a party and I wanted to have some fun. In the darkened room, we saw that a student's teeth lit up brilliantly under the ultraviolet, but he seemed to have on of his front teeth missing. When we turned the room lights on, we saw that he had a false tooth. It did not fluoresce. I exclaimed: "New light, new knowledge!" That was precisely the point. And that is why your Advanced Light Source is so important. Its new and powerful invisible light will surely bring forth new knowledge.

A young woman arrived late at the party. She heard about the demonstrations from the other students. She said: "I read somewhere that diamonds fluoresce under ultraviolet. I've just gotten engaged and I'd like to look at my ring under the ultraviolet light. We dimmed the room lights. She put her ring under the ultraviolet lamp. It did not fluoresce! New light, new knowledge!

There may not have been money for research in those days but there was excitement! I remember clearly how excited I was when I watched the image on a fluorescent screen, in a darkened room and with dark-adapted eyes, of x rays which had been reflected at grazing incidence from a flat plate of glass. As I turned a screw which operated a device that curved the mirror, I observed the focusing effect which it produced. Eureka! I had focused x rays! Soon we were using a pair of mirrors at right angles to one another and obtained enlarged two-dimensional x-ray images of two-dimensional objects. We had the makings of an x-ray microscope!

Before long, PK obtained financial support from the Research Corporation and many other graduate students followed: Jim McGee who designed and built complex multi-mirror systems to correct aberrations, and Leonard Rieser who used grazing incidence reflectors to focus neutrons. There were many others like Howard Pattee and Ralph Wuerker whose contributions escape my memory.

If you want more than anecdotes about the early days of x-ray optics, however, you must read the report of the first International Symposium on X-ray Microscopy and Microradiography which took place in Cambridge, England in 1956. It had been sponsored by the International Union of Pure and Applied Physics and organized with financial support from UNESCO—two organizations which would play an important role in my professional life later on.

In Cambridge, we learned that there was a lot going on worldwide in the field we now call x-ray optics. PK and Dennis Gabor met for the first time. Several of PK's students beside myself also attended and reported on our work. We met Cosslett and Nixon of Cambridge who had designed a marvelous x-ray source with an extremely small focal spot. In short, it was an exciting experience which I do not have the time to describe.

The Impact Of Holography

Instead, let me talk about an invention which had a strong influence on the direction which PK's research would take. This was holography invented by Dennis Gabor. His seminal paper was published in 1948, the same year that the first paper on the grazing incidence x-ray microscope was published in the Journal of the Optical Society of America. PK sensed that holography might open a door for another approach to x-ray microscopy without mirrors or lenses. Gabor had actually made what we now call an on-line hologram with a point source of light and a filter to prove the feasibility of holography which he hoped to use to improve the electron microscope.

PK sent his graduate student Hussein El-Sum to study Gabor's paper and to reproduce his experiments in order to understand holography for the purpose of exploring the possibility of using it for image formation with x rays. El-Sum's dissertation was the first serious experimental and theoretical study of holography. He was besieged by requests for reprints. It became, in effect, the basic handbook on holography before the invention of the laser and the contributions of Leith and Upatniks.

After Stanford, I went to teach at the University of Redlands, a small liberal arts college with no track record in scientific research. But the Research Corporation urged me to consider doing research on holography and x-ray optics with undergraduates and they awarded me a small grant. I got much pleasure out of working with undergraduates during the summer vacations. I have since been a strong advocate of research done by undergraduates.

At Redlands, I too became interested in making an x-ray on-line hologram and realized that its success depended on having a very small point x-ray source. Mind you, this was ten years before the invention of the light laser and thirty years before the development of an x-ray laser so we were still thinking in terms of on-line holography.

Cosslett and Nixon of the University of Cambridge in England had designed and built an x-ray tube whose focal spot was about a micron in diameter, so I convinced the National Research Council to pay for a travel grant to bring Nixon to Redlands to work with me and with El-Sum who was also there.

If we had understood spatial and temporal coherence better, we would have known that a one micron x ray focal spot was still much too large to produce an on-line hologram with radiation whose wavelength was about ten angstrom units. But the Cosslett-Nixon tube produced beautiful point projection x-ray shadow pictures of remarkable clarity and resolution and we made many of these. It was an x-ray microscope of sorts.

I made many Gabor-style holograms with visible light. They always exhibited diffraction patterns consisting of concentric circular bands. In fact, the hologram of an infinitesimally small dust spot on a glass plate turns out to be a Fresnel zone plate pattern. This is easy to prove experimentally because the successive circles which are the boundaries of the bands have radii that increase as the square root of the integers. In fact, G.L. Rogers in England devised a theoretical explanation of on-line holography which is based on the idea that a hologram is a complex pattern of Fresnel zones. It gives very good quantitative results and a wonderful neuristic explanation of holography.

The Fresnel Zone Plate For X-Rays

Seeing all those circular fringes in the early holograms led me to consider the possibility of producing a single Fresnel zone plate of focus x rays. Around 1959 the techniques of making metal masks by using photoresist and electrodeposition was well established and it suggested to me that, if I drew a zone plate pattern on a piece of paper and added some radial struts, the resulting metal mask would be self-supporting.

I obtained financial support from Professor Whipple at the Smithsonian Astrophysical Observatory in Cambridge to produce a zone plate that could focus x rays. I then got the Buckbee Mears Company in Minnesota to do this for me and we ended up with a gold metallic Fresnel zone plate which was self-supporting. Its open bands were transparent to radiation of all wavelengths because they were empty. Its opaque bands could stop soft x rays because they were made of gold.

I was working in a hurry because I had already accepted a post with UNESCO in Paris. For lack of an x-ray source, I tested the zone plate with an ultraviolet source. It worked according to predictions so I knew it would work with all x-ray wavelengths that could be stopped by the gold bands. To the best of my knowledge, this was the first Fresnel zone plate capable of focusing x rays.

I immediately submitted a letter to *Nature* announcing our results. I then submitted an extended paper to the Journal of the Optical Society of America and I read a brief paper on the subject at a Boston Meeting of the Optical Society of America—all of this just before leaving for UNESCO in Paris. I later learned that Gabor had been a referee on my letter to *Nature*.

Nested Mirrors—The Venetian Blind Configuration

The other contribution I made while at the Smithsonian Astrophysical Observatory in Cambridge was to explore the possibility of increasing the flux that can get through a grazing incidence x-ray image forming device. Imagine that you have not one horizontal mirror but a set of parallel mirrors nested in a venetian-blind-like configuration so that a parallel beam of x rays hits all of them at grazing incidence. Then imagine another nested set beyond the first but at right angles to it and you have a grazing incidence x-ray microscope or telescope with high throughput.

I tried it first with flat mirrors to illustrate the idea and later with curved mirrors to improve the resolving power of the instrument. It was reported in the Journal of Geophysical Research because of its potential use as an x-ray telescope and that may have been a bad choice because it was probably not read by the practitioners of x-ray optics. To the best of my knowledge, this was the first use of such pairs of nested arrays of mirrors for grazing incidence x-ray image formation designed for high throughput. Today, they are incorporated in the plans for the so-called LAMAR-x-ray telescope.

To my delight, then, approximately 40 years after PK's initial contribution to x-ray optics, I read the citation in the 1991 SPIE Dennis Gabor Award which reads: "Today Kirkpatrick-Baez x-ray microscopes are routinely employed at laser fusion facilities. The Kirkpatrick-Baez LAMAR x-ray telescope has been approved for flight on the FREEDOM Space Station."

Recent Developments

I am, of course, in awe of the developments that have taken place in x-ray optics in the interning years. Ceglio has described them well in the first issue of the new *Journal of X-Ray Science and Technology* in an article called "Revolution in X-Ray Optics."

Some of you might be curious as to why I did not continue working in this potentially dynamic field. I guess the main reason was that it was not recognized immediately as potentially dynamic. There were no jobs connected with it. Academic physics departments were not supporting it—witness Stanford immediately after Kirkpatrick's retirement.

I continued teaching and working with groups like the Physical Science Study Committee (PSSC) which got started in the late 50s at MIT under Jerrold Zacahrias. When Sputnik was launched Zacahrias obtained funds for a vigorous activity to improve the teaching of high school physics in the U.S. I joined his group and became the studio physicist during the production of its first ten films.

Later, on the basis of my experience with PSSC, I was invited by UNESCO to come to Paris to establish a new division whose objective was to improve the teaching of the basic sciences world-wide; especially in the developing countries.

So I spent 6 years in Paris generating Pilot Projects to develop new tools for teaching and learning science. We started one new Pilot Project every two years. First, Physics in Latin America; next, Chemistry in Asia; then, Biology in Africa; and finally Mathematics in the Arab States.

Since my research experience got started relatively late—I was already 36 when I received my Ph.D.—the years flew by in teaching, curriculum reform, and the production of teaching films and suddenly it was time to retire. So I retired.

Or did I? It has been a peripatetic retirement. During the past 15 years, I have been lecturing sporadically in many countries around the world. More than ten years ago, I was asked if I would be willing to come to Ireland as a Tyndall lecturer to deliver lectures on holography in five Irish universities. I said, "just wave a pre-paid ticket in front of me and see what happens." As a result, I have traveled all over the world in my retirement. I have three engagements already for 1994. One is in the city of Pueblo, Mexico where I was born. So you can imagine the fun I am having seeking my roots.

It's a pleasure to be here. I feel like Rip van Winkle. I am delighted to see that you have developed this sophisticated and powerful new light source. I congratulate all those who were involved in its invention and its construction. I have no doubt that it will generate new knowledge beyond our expectations.

High-Resolution Soft X-Ray Spectroscopy

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The present state in high-resolution spectroscopy with the SX700/II monochromator operated by the Freie Universität Berlin at the Berliner Elektronenspeicherring für Synchrotronstrahlung (BESSY) is reported. This includes both inner-shell photoabsorption studies of atoms and molecules as well as photoemission studies of rare-earth materials in the photon-energy range from ≅ 40 to ≅ 900 eV. In addition, the recently discovered large magnetic circular dichroism (MDC) in 4f photoemission from magnetized rare-earth materials is briefly discussed.

The SX700/II beamline is based on a plane-grating grazing-incidence monochromator without entrance slit, positioned at a bending magnet of BESSY. Its central optical element is an ellipsoidal mirror that focuses the source of radiation onto the exit slit. Manufactured by Carl Zeiss, Oberkochen, the monochromator was gradually optimized by Michael Domke and is presently operated with a high-precision ellipsoidal mirror with an angle-tangent error of ≤ 0.65 arc sec, a 2442 l/mm grating, and exit slits with widths as small as 5 µm. With a single grating, high resolution can be obtained in the whole photon-energy range from ≅ 40 eV to ≅ 900 eV.[1]

The presently unique features of the SX700/II beamline are expressed in the photoionization spectra of He in the double-excitation region from ≅ 60 eV to ≅ 78.3 eV. The three E1-allowed $1P^o$ Rydberg series converging to the second ionization potential, IP_2, of He represent an optimum test for resolution and flux around 65 eV. Rydberg states up to n = 20 could be resolved for the strongest "+" series in the nomenclature by Lin [5], and the extremely narrow and weak resonance lines of the long "hidden" (2p,nd)1Po-series $\left(1(-1,0)_n^0\right)$ were well resolved up to n = 8.[3] Similar detailed spectra could be taken for the $3(1,1)_n^+$, $4(2,1)_n^+$, $5(3,1)_n^+$, and $6(4,1)_n^+$ series,[1,4] as well as for the strong-interference region of the $7(5,1)_n^+$, $8(6,1)_n^+$, and $9(7,1)_n^+$ series up to the $10(8,1)_{10}^+$ state. Anomalies in line widths, peak amplitudes, and Fano profiles due to interferences were studied in detail for the N = 5 and 6 resonances,[4] and compared with recent theoretical results.[6-8]

Furthermore, inner-shell photoionization was investigated for a series of small molecules in the gas phase. From the vibrationally-resolved core-excitation spectra taken at the K-thresholds of F, C, N, and O and the L-thresholds of S, information on energies and splittings of unoccupied orbitals, on core-hole decay rates, on structural parameters of the core-excited molecules as well as on vibronic coupling are obtained. We refer to two recent Ph.D.-thesis solely based on data from the SX700/II [4,9] as well as to a series of publications.[10-15]

In the second part of the talk, we reported on recent progress in soft x-ray photoemission (PE) from solids, in particular from rare-earth materials. Employing a high-resolution hemispherical electron analyzer (from Leybold-Heraeus, LH-EA11 at the SX700/II beamline 4d→ 4f resonant PE with a total-system resolution of 25 meV (FWHM) has been achieved.[16] This allows a direct study of the 4f-electronic structure of Ce and its compounds in the bulk and at the surface[16-18] as well as new insight into the low-energy excitations of these highly correlated electron systems. In addition, surface core-level shifts of 4f levels as well as d-like surface states have recently been studied with high precision for well-ordered close-packed surfaces of rare-earth metals.[19,20] The surface core-level shifts were found to be by a factor of ≅ 2 smaller than the experimental and theoretical values in the literature. By comparing the surface core-level shifts of electron-removal 4f states (obtained by PE) with those of electron-addition 4f states (obtained inverse PE[20,21]), a separation of surface core-level shifts into initial-state and final-state contributions could be achieved.[20]

Finally, the recent discovery of large magnetic circular dichroism in 4f PE (MCD-PE) from ferromagnetically ordered rare-earth metals (Gd, Tb) is briefly discussed.[22,23] The MCD-PE asymmetries were found to be as large as 67% in case of TBFe2 at T = 110 K. Since the MCD-PE effect can be quantitatively described by atomic calculations in these highly localized systems,[24] it can also be applied to determine the degree of circular polarization of soft x-ray beams over a wide photon-energy range from ≅ 40 eV up to several thousand eV. As shown for remanently-magnetized Tb(0001) metal grown on W(110), the MCD-PE effect in conjunction with a well-resolved surface-shifted 4f signal offers new possibilities for the study of surface magnetism. The bare magnitude of the MCD-PE effect promises interesting perspectives for magnetic surface microscopy.

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Soft X-Ray Emission Spectroscopy

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The new high brightness synchrotron radiation sources open up many new interesting possibilities for applying high resolution soft x-ray emission spectroscopy (SXES) to the study of various problems in materials science and molecular physics.[1] Soft x-ray emission spectroscopy offers a unique means to obtain information about the chemical state of atoms in bonded systems due to the simultaneous involvement of both inner electrons and the valence electrons. This allows the local electronic structure to be studied in terms of separated symmetry resolved contributions from different atomic species to the valence band.

Apart from the high brightness offered by synchrotron radiation sources and which makes soft x-ray fluorescence feasible at all, the selectivity with respect to both energy and polarization of the exciting photons provided by synchrotron radiation refines the inherent information potential further and adds new means to obtain detailed knowledge about the electronic structure. This allows for instance the interactions of molecules bonded to a surface to be investigated in detail, since one can separate the contributions from the molecule's electrons from the substrate derived contribution to the valence band (the latter is often dominating in photoemission spectra).[2] In non-isotropic systems like adsorbate overlayers, the polarization and angular aspects of the experiment are essential, and it is indeed feasible to extract the directional components of the orbitals of a bonded molecule by fully utilizing these parameters of variation. In this way one can get detailed information about the hybridization in the bonding of a chemisorbed system.

Studies of chemical and physical processes at surfaces are vital for the understanding of many technically important chemical processes, and many different methods are applied in such work. The ability of soft x-ray emission spectroscopy to separate the different atomic contributions to the valence electronic structure of molecule-metal bonds has been demonstrated, and of particular interest is the possibility offered by SXES of studying an interface of a solid and a gas under relatively high pressure, something which is generally impossible with many of the commonly applied methods. This allows one to study systems of higher technical relevance, and it offers a new means to obtain knowledge which is essential for environmental technology and process industry.

It has been shown that one can use soft x-ray emission to monitor reactive deposition processes *in situ* and in real time.[3] This opens possibilities in technical applications where one wants to monitor in detail the growth of a film. One example presently subject to experiments is CVD deposition of diamond films. We have found that due to resonant inelastic processes the detailed ordering of the carbon atoms in a diamond film in a sensitive way affects the x-ray emission spectrum .[4] This is the basis for the attempted method to use emission spectroscopy to make *in situ* characterization of a growing diamond film.

The inherent selective properties of soft x-ray emission allows one to obtain partial density of states projections with respect to different atomic species of a multi-compound sample. With monochromatized photon excitation one can also obtain site specific information (for the same atomic species) due to the tunability of the excitation. This has been applied to studies of superconducting cuprates, where the effect of hole doping has been revealed in terms of site selection and orbital symmetry character.[5] The latter information has been obtained by, in addition, conducting angular resolved studies and making use of the linear polarization of undulator radiation.

Magnetic circular dichroism in x-ray absorption spectra has rapidly grown to a widely spread method to study magnetic properties of matter. In a recent experiment circularly polarized and energy bandpassed photons were used to excite soft x-ray fluorescence from a magnetic sample in order to study magnetic circular dichroism in emission spectra. The results showed that one can indeed use this method to obtain new information about the element specific ground state magnetic properties of multi-element magnetic structures, also for buried magnetic layers. Further experiments also showed that interface layers can be distinguished from the bulk, which has important implications since one has observed that extreme magnetic properties can appear at interfaces.

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X-Ray Dichroism

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Sum rules are derived for linear and circular dichroism in the x-ray region. They relate the integral of the dichroic signal, over a single partner of a spin-orbit slip edge, to the ground state expectation value of effective operators (orbital and spin dependent moments), allowing for a simple interpretation of the observed spectra. Applications are discussed to transition metals, rare earth, and actinides.

Application of VUV Undulator Beamline to Chemical Dynamics at the ALS

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Purpose

A new program will be initiated at the Lawrence Berkeley Laboratory (LBL) to explore applications of synchrotron radiation at LBL's Advanced Light Source (ALS) in chemical dynamics, which encompasses all phenomena in which molecules undergo energetic or chemical transformations and to provide the experimental facilities needed for the exploration. The ALS will be used as a photo-analysis source to produce high yields of vacuum ultraviolet photoionized products. If operated in conjunction with powerful lasers, the Light Source will additionally be a powerful tool for the study of chemical processes induced by multiphoton absorption. Its time structure permit the study of ultrafast processes. These studies will culminate in research to determine the microscopic details of the mechanisms and dynamics of primary dissociation processes and elementary chemical reactions; to explore the chemistry of molecules excited to a Rydberg state or to other superexcited states; to study the structure, energetics and chemical reactivity of highly reactive polyatomic radicals and unusual transient species; to probe the nature of inter-and intra-molecular energy relaxation; and to search for bond-selective means to modify and manipulate chemical reactivity.

Approach

The experimental approach involves combining a synchrotron radiation source, lasers, molecular beams, and molecular and spectroscopic detection techniques to carry out the proposed research. The ALS U8.0 undulator beamline will be modified and a new branchline constructed to deliver a high intensity (10^{15} photons/sec), low resolution (2.5%) VUV beam for selective photoionization and product detection in primary photodissociation and photofragmentation studies. This branchline will feature a differentially pumped gas filter to suppress unwanted orders of the undulator radiation, and toroidal mirrors that focuses the synchrotron light to a spot of ~ 100 μm. The ability to focus a small spot size is a special characteristic of undulator radiation. It will lead to highly improved mass and energy resolution in ion and electron detection in the proposed experiments.

Standard lasers in the IR, Visible, and UV, and specially fabricated high-power, high-resolution lasers in the mid-IR and VUV will be used in conjunction with the undulator beamline to carry out pump-probe and state-to-state selective dynamics experiments throughout the optical region of the electromagnetic spectrum.

The Chemical Dynamics Beamline

1. Design and fabrication of branchline at the ALS U8.0 undulator beamline. It is necessary to modify the existing U8.0 beamline so that VUV photons can be deflected, filtered, and refocused into the molecular beam chamber. A new toroidal mirror and associated vacuum chamber will be inserted as the deflector that also serves to squeeze the photon beam through a differentially-pumped high-order suppresser. This high-order suppresser is used to absorb unwanted high energy photons that are found in abundance in the undulator beam. A second toroidal mirror then recollimates the beam to a cross-section of the order of 100 μm x 0.5 mm located at the detector ionization region or at the point where two molecular beams cross in the sample chamber. The VUV beam is then sent through a normal incidence monochromator to provide

light for experiments that require higher resolution than the undulator can produce. The U8.0 undulator will be replaced by a 10-cm period undulator (U10) at the first shutdown in 1995. This beamline will be optimized for photon energies in the 5-30 eV range ideal for probing chemical interactions.

2. Design and fabrication of molecular beam experimental station. Two stations are planned. One will be designed for experiments requiring the highest available VUV fluxes and one will be for experiments that need to utilize higher resolution than the 2.5% bandwidth that the U8.0 undulator normally provides. It is anticipated that the majority of experiments will fall in the former category.

The first station will be a universal rotating-source crossed-molecular-beam apparatus designed to use the ALS as a photoanalysis source. The tunable output from the U8.0 undulator will be used directly, without additional frequency filtering. The apparatus will be designed for studying primary photochemical processes and dynamics and reactivity of polyatomic molecules, ions and clusters, using photofragmentation translational spectroscopy. The ALS beam will be shaped and transmitted through the ionizer region of the conventional TOF mass analyzer and serves to ionize photodissociation products. This unique approach is advantageous for product detection because it provides both improved species selectivity and reduced background detection. Alternatively, for certain experiments, the ALS beam will be directed to the molecular-beams interaction region to be used as an excitation source. In this case, an electron impact ionizer will be used in the same TOF apparatus. Differential pumping will be employed extensively to protect against systematic and accidental contamination of the synchrotron beamline and storage ring apparatus.

Experiments that require a higher resolution than the 2.5% bandwidth that the U8.0 and U10.0 undulators can provide will be performed in a second station. The ALS beam exiting from the first station will be passed through a 1-m normal incidence monochromator to obtain a 100-fold improvement in wavelength resolution. This monochromatized beam will be collimated and delivered to a molecular beam apparatus. The apparatus will be "conventional" in design, equipped with a TOF mass spectrometer and a zero-electron-kinetic-energy (ZEKE) spectrometer. Since this station will be located further downstream from the storage ring, the vacuum protection requirements will be less stringent. This station will be particularly useful for studying VUV and IR spectroscopy of superexcited molecules, free radicals, and other transient species.

Molecular source chambers for generating radicals, ions and clusters, both CW and pulsed, will be constructed to be used at both stations. Oil-free vacuum equipment will be employed for all chambers. Tunable lasers for pump-probe experiments will be included.

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APPENDIX A

Program
ALS Users' Association Annual Meeting
Lawrence Berkeley Laboratory
October 21-22, 1993

Wednesday Evening, October 20:

6:00 – 8:00 p.m.	Registration: Shattuck Hotel	

Thursday, October 21:

Scientific Opportunities at the ALS

(Chair: Francois Wuilleumier, University of Paris)

8:30 – 8:45	Welcome	C.V. Shank, Director, LBL
8:45 – 9:30	Overview of the ALS	B. M. Kincaid, Director, ALS
9:30 – 10:00	The ALS into the 21st Century	D. A. Shirley, Pennsylvania State University
10:00 – 10:30	BREAK	
10:30 – 11:00	Report from the DOE	W. Oosterhuis, DOE/BES
11:00 – 11:30	Scientific Program at the ALS	N. Smith, Scientific Program Head, ALS
11:30 – 12:00	Industrial Opportunities at the ALS	G. H. Dahlbacka, Technology Transfer Department, LBL
12:00 – 14:00 p.m.	Box Lunch, Vendor Exhibit, Tour	Building 6

Working at the ALS and Microscopy

(Chair: Ben Feinberg, ALS)

14:00 – 14:45	Experimental Facilities	H. Padmore, Leader of Experimental Systems Group, ALS
14:45 – 15:15	ALS User Program	A.S. Schlachter, Leader of User Liaison Group, ALS
15:15 - 15:30	Working Safely at the ALS	G. Perdue, EH&S Safety Rep., ALS
15:30 – 16:00	BREAK	
16:00 – 16:45	Micromachining	R. White, University of California, Berkeley
16:45 – 17:30	X-Ray Microprobe	A. Thompson, Center for X-Ray Optics, LBL
17:30	Adjourn	
19:00 – 19:30	Reception	Hong Kong East Ocean Seafood Restaurant
19:30	Conference Banquet	Speaker: Dr. Albert V. Baez Subject: "The Early Days of X-Ray Optics"

Friday, October 22:

Spectroscopy

(Chair: Piero Pianetta, SSRL)

8:30 – 9:00		XSW (X-Ray Standing Waves) and XPS (X-Ray Photoemission) in the Soft X-Ray Region	G. Materlik, HASYLAB/SSRL
9:00 – 9:45		High-Resolution Spectroscopy	G. Kaindl, Freie Universitat Berlin
9:45 – 10:30		Soft X-Ray Emission	J.E. Nordgren, University of Uppsala
10:30 – 11:00		BREAK	
11:00 – 12:00		ALS Dedication Ceremony	Building 6
12:00 – 13:30	p.m.	Box Lunch and PRT Meetings	

Magnetic Circular Dichroism, Chemical Dynamics, Biology

(Chair: Phil Heimann, ALS)

13:30 – 14:15	MCD Theory	P. Carra, ESRF
14:15 – 15:00	X-Ray MCD of Metals and Biology	Steven Cramer, University of California, Davis; LBL
15:00 – 15:30	BREAK	
15:30 – 16:15	Chemical Dynamics	Yuan Lee, University of California, Berkeley
16:15 – 16:45	User Meeting	D. Ederer, Chair
16:45	Adjourn	

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