**Undulator Spectromicroscopy Facility
at the
Advanced Light Source: Annual report 1992**

1.0 Introduction

Note: the following description of the project is adapted from an article written for the ALS newsletter.

To understand how the SpectroMicroscopy Facility concept evolved, it is necessary to understand the characteristics of the U5 undulator as implemented by Brian Kincaid and his team at the Advanced Light Source. To see what this unique X-ray source is like, consider the following performance value. At 100 eV, near the peak of the U5 output, the undulator will produce 80 milliwatts of X-ray energy into a bandwidth of only one-tenth of an eV. Because the ALS storage-ring emittance is so low, a large fraction of this radiation diverges at a rate set by the photon wavelength rather than by the electron-beam angles. Thus, the source has high spatial coherence, and puts the 80 mW X-ray beam into a spot size less than two millimeters in diameter as far away as 20 meters from the undulator. From the point of view of the experimentalist, for many purposes, this beam will function as if it were a tunable, CW, soft X-ray "laser".

The laser-like quality of the U5 undulator beamline is used in a variety of ways, depending on the experiment. Perhaps the most direct impact of the undulator's narrow beam divergence is to abate the intrinsic limitations of soft X-ray monochromators, which must be used with very shallow reflectance angles. With the U5 undulator, a world's record resolving power can be achieved over a range of 100-1000 eV, while at the same time improving the photon flux over that of existing X-ray sources, both in the laboratory and at synchrotrons. Other experiments will use the spatial coherence of the X-ray beam in novel ways, such as for microscopy and coherent soft X-ray scattering from surfaces.

The SpectroMicroscopy Facility is a Participating Research Team (PRT) that was formed to design and build detectors and experimental stations that could take advantage of the specific advantages that the highly coherent undulator source provides. The primary scientific orientation of the team is in materials science and the physics and chemistry of surfaces or interfaces. The SpectroMicroscopy Facility is organized as an ALS "Type A", project. It includes members from the ALS, UC-Berkeley, the University of Michigan, the University of Oregon, Pennsylvania State University, University of Wisconsin, Lawrence Livermore National Laboratory, Stanford Synchrotron Radiation Laboratory, and LBL-Center for X-ray Optics. Construction of the analytical equipment for experiments on the U5 beamline is funded by a field-task proposal through LLNL (J. Tobin and B. Tonner, co-principal investigators), and by this proposal.

Given the unique characteristics of the undulator and monochromator, considerable thought was given to finding a way to "multiplex" the use of the monochromatic beam. Unlike laser sources, or even hard X-ray synchrotron sources, in the soft X-ray region of the spectrum most of the experiments are performed under high or ultra-high vacuum

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conditions. In addition, beam steering can only use optics at very shallow reflection angles. These factors make it logistically difficult to switch the X-ray beam from one experiment to the next without a lot of "downtime". A good solution to this problem has been found by Tony Warwick of the ALS staff, who is also a PRT member. The idea is to use a set of refocussing mirror optics to switch the beam from the monochromator into two separate experimental chambers, located at different distances from the monochromator exit slit. This allows two experiments to be coupled to the monochromator at the same time, both of them under vacuum. Switching the beam from one station to the next can be done in a matter of minutes, so that experiments can time-share at ALS on a flexible schedule, and use the beamline 24 hours a day.

Experimental stations are being constructed around a set of detectors for both charged particle and photon spectroscopy. Included in the set of experimental capabilities are high resolution photoemission, photoelectron diffraction, X-ray absorption fine-structure (both electron and fluorescence detection), soft X-ray fluorescence spectroscopy, soft X-ray scattering, and photoemission microscopy. These detectors will be supplemented by additional equipment specific to the research interests of the PRT members, including such capabilities as electron diffraction, scanning-tunneling microscopy, and molecular beam epitaxy.

The first experimental station that will operate on the new U5 beamline will contain the photoelectron spectroscopy and diffraction system. This system is expected to become one of the most widely-used instruments of the SpectroMicroscopy beamline, because of the central role played by photoemission techniques in the analysis of surfaces and interfaces. This instrument will combine exceptional energy and angular resolution with very high photon flux. Experiments that are now either impossible or exceedingly difficult will become the mainstay of this detector station. One example is XPS of surface reactions with millisecond time resolution, made possible by the very high photon flux coupled to multi-energy detection in the electron spectrometer. Another example is photoelectron diffraction and holography with energy resolution sufficient to isolate surface atoms from the bulk background. Photoelectron diffraction-pattern experiments, although possible with laboratory sources, are currently struggling with low signal rates that limit the range of samples that can be studied to those that are stable over the many hours required for data acquisition.

The U5 photoelectron spectroscopy station will be one of the first in the world to implement the technology for optimized XPS or electron spectroscopy for chemical analysis (ESCA). Called "ultraESCA", this concept employs an undulator source to produce a tunable X-ray beam with 0.1 eV or better energy resolution, photon flux of 10^{11} to 10^{12} and above, into a spot size below 50 micron diameter. In an ultraESCA design, the state-of-the-art X-ray optics are coupled to a modern multi-detection electron spectrometer capable of high energy resolution and fast spectrum acquisition.

Aggressive goals have been set for another SpectroMicroscopy detector system, the scanning photoemission microscope (SPEM) and the scanning transmission X-ray

microscope (STXM). These X-ray microprobes use zone-plate lenses to focus the monochromatic beam from the U5 monochromator into a diffraction-limited spot. The SPEM will run in ultra-high vacuum, and will be used for photoemission microscopy and X-ray absorption microscopy of surfaces. The STXM is an air microscope, and will have a transmission detector and fluorescence yield detector for microscopy from both surfaces and thin sections of materials. Dave Attwood, Director of the Center for X-ray Optics and a member of the PRT, says that CXRO is working to develop zone-plates with an ultimate resolution of 250 Angstroms for the SPEM and STXM instruments.

2.0 Scheduled PRT design meetings

Regularly scheduled PRT meetings have been held (or will be held) on the following dates:

- May 2, 1992: Allen, Kortright, Kevan, Olmstead, Pianetta, Tobin, Tonner, Warwick, Willis
- August 26, 1992: Ade, Attwood, Bokor, Kortright, Kevan, Olmstead, Pianetta, Tobin, Tonner Underwood, Warwick, Willis
- October 4-5, 1992: (microscope design sub-group): Ade, Tobin, Tonner, Warwick
- December 10, 1992: (microscope design sub-group)

2.1 Meeting notes (abridged), May 2, 1992

Tony Warwick presented the latest ray-tracings, flux expectations and beamline layouts for the U5 beamline. An added plane mirror makes the exit beam horizontal, and refocused spot sizes will be at the 50 micron level or smaller. It is planned to have a fixed-radius vertical refocus mirror made, optimized for a particular scan range, to use during the early days of beam time.

A multilayer-mirror branch line was proposed, that will be used for experiments that require the natural coherence of the undulator. The branch line will require a water-cooled multilayer coated mirror with different stripes of multilayer spacings for different wavelengths. Potential locations for the multilayer mirror in the existing beamline layout will be examined for discussion at the next meeting. Planned experiments on the branch line include a scanning fluorescence microprobe, soft X-ray speckle time dynamics, and soft X-ray scattering.

Specifications for the photoemission station were discussed at length. Performance characteristics for the sample goniometer and electron spectrometer were determined.

Jim Allen presented plans for experiments to study the time dependence of coherent soft X-ray scattering, or "speckle scattering." These experiments are possible on the U5-SGM branch lines, but are also suited to the new multilayer branch line mentioned above.

2.2 Meeting Notes (abridged): August 26-29, 1992

A letter of request for membership on the PRT board was received from Dr. H. Ade. Ade was elected to the board by a unanimous vote.

Bid specifications were drawn up by Tobin and Tonner for the the XPS/XPD (X-ray photoelectron diffraction) station based on the results from the May 2 meeting, for the X-ray spectrometer and the sample goniometer. These specifications were circulated to potential vendors for comments. A major issue for the electron spectrometer is the specification for the minimum resolvable line-width, demonstrated by the vendor. If this number is set very small (below 15 meV), the number of options for vendors is drastically reduced. Equipment required for the XPS/XPD station includes reverse-view LEED, UPS light source and/or XPS light source, sample intro/transfer, and a frame-trolley system for rapid removal of the chamber from the beamline.

An XPS/XPD subgroup was formed (Olmstead, Pianetta, Tobin, Willis) to exchange potential chamber designs.

Warwick and Kortright presented preliminary design ideas for the multilayer branch line. A location in the beamline for a 24 degree total deflection was found. Heat load deformation of optics and multilayer degradation are a concern.

A first draft chamber layout for the scanning photoemission microscope (SPEM) and the scanning transmission Xray microscope (STXM) was discussed. The SPEM (Nanofocus I) and the STXM (Nanofocus II), use the beamline station Microfocus I as the object point for a demagnification of about 2000X. Microfocus II is the XPS/XPD station.

2.3 Meeting notes (abridged): October 4, 1992

This meeting was devoted to identifying the major components for the Nanofocus I and II microscopes, and agreeing to a base-line design.

The object point for the Nano-I and Nano-II has been moved from the focus of Micro-I, to a point approximately 0.5 meters downstream. This will allow Micro-I to be used for additional spectroscopic experiments.

The design of the pinhole manipulator will be based on a water-filled low-vibration column, taken from the ALS entrance and exit-slit designs. The pinhole is not mechanically coupled to the microscopes. Calculations show that this can be tolerated with the low-vibration stands.

The SPEM is located approximately 4 meters from the pinhole. Light can be passed through the SPEM and out a window to run the STXM. Both the SPEM and the STXM will share a common vibration-isolated table.

The SPEM is a UHV design. It was determined that the zone-plate can be scanned to generate an image, as opposed to the usual technique of scanning the sample. This is because the area of the X-ray beam is several times larger than the zone-plate at the Nano-I position. By scanning the zone-plate, the mechanical requirements on the sample manipulator are substantially reduced, so that more sophisticated sample processing is possible.

Specifications for the zone-plate manipulator for the SPEM were agreed upon. The zone-plate manipulator will have a series of UHV stepper-motor driven linear stages, carrying a piezoelectric flexural-hinge stage for the fine motion.

The STXM has similar tolerances on the scan motions. The STXM will have a low-vacuum housing to allow for runs in helium atmospheres or modest vacuum.

A design for a transmission-grating soft X-ray detector for the STXM was outlined.

3.0 Project status (progress to date)

The overall Facility layout has been finalized. There will be four stations implemented during the first year of ALS operations: MicroFocus I and II, and NanoFocus I and II.

The design of the horizontal exit mirror assembly and vertical refocussing optics was completed, and is in the queue for construction at ALS. These optics send photons to MicroFocus I and II. MicroFocus I will be used for X-ray absorption near-edge spectroscopy, and is also located near the pinhole objective for NanoFocus I and II, which are the two X-ray scanning microscopes. MicroFocus II is for the XPS/XPD spectrometer.

The first priority of the project is to have the XPS/XPD station working on the ALS "day one". For this project, Day One corresponds to the point at which monochromatic light is available from the beamline with about 100 mA of stored current in the ring. This is now estimated to be in late August or early September.

This time-line sets a hard and fast deadline of late February for the ordering of the XPS/XPD station. For practical reasons, the sample goniometer was placed out for bid separately from the rest of the spectrometer. The sample goniometer design requires some revisions to insure compatibility with the STM and XPS spectrometer, whose design is now being finalized. A system design has been done which includes the XPS spectrometer, sample goniometer, alternate (vertical) sample goniometer, STM, reverse view LEED, ion sputtering, sample introduction, and ports for evaporators and X-ray source. The design work is nearing completion as of this writing. A target date of Dec. 1 has been established for finalizing the system specifications (complete with CAD drawings) to go out for bid.

4.0 Project plan for the next grant year

4.1 XPS/XPD system

Design work on this system is nearly completed. This system will be the first experimental station operating at ALS. It will be used initially to characterize the resolution of the monochromator and do calibration work. Experiments during the first year are planned for resonant photoemission, X-ray absorption, and photoelectron diffraction.

4.2 STXM

Since the scanning transmission X-ray microscope does not require UHV, its components can, for the most part, be purchased as stock items and assembled without extensive machine work. Therefore, a decision has been made to bring the STXM on-line as early in the first year of ALS operations as possible. The majority of the components of the STXM will be purchased in time to assemble the microscope beginning in the late summer of 93 (i.e. just before experiments can begin on the XPS branch).

4.3 SPEM

This is the UHV X-ray microscope. There is substantial design work required for the zone-plate scanner. The vacuum chamber, sample manipulator and electron detector will be ordered for delivery in Sept-Oct. of 93. The SPEM will be the only project required major design work during the next year, and is scheduled to be fully operational by March of 1993.

4.4 Software development

Due to the highly automated, microprocessor driven, network intensive environment at the ALS, it is anticipated that there will be a demand for new software that cannot be immediately met. Experiment "shells" are to be written during the upcoming year, using C++, that contain the basic outline of subroutine calls necessary to drive the monochromator and collect X-ray absorption data and XPS data. It is expected that there will be about one full-time graduate student needed just to write code, by the end of the next grant year.

5.0 Attachments

Meeting summaries and technical notes generated during the past 8 months are attached.

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