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SOFT-X-RAY AND VACUUM-ULTRA VIOLET BEAMLINES AT THE NATIONAL SYNCHROTRON
LIGHT SOURCE 700-MeV STORAGE RING*

by

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We summarize the characteristics of the first beamlines which are being installed and commissioned at the National Synchrotron Light Source (NSLS) 700 MeV storage ring at Brookhaven National Laboratory. We also give a progress report as of July 1982 on the early stages of beamline alignment and operation in which particular attention is paid to the 5 beamlines which NSLS has developed. The report describes in detail a novel method for beamline alignment which is of general application.

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I. INTRODUCTION

This paper is intended as a progress report of activity to date (July 1982) at the NSLS VUV ring.

Since the achievement of the first stored beam in the NSLS VUV ring in December 1981 a considerable number of beamlines have become operational. At the time of writing the hardware for 9 beamlines is on the VUV floor and delivery and installation of 7 more beamlines is imminent; six are now receiving beam.

Table I summarizes the assignments of the 16 ports on the VUV ring and describes the beamlines which are being installed on the ports. The actual locations of the ports and beamlines are shown in Fig. 1 which also shows some of the hardware. Figure 2 is a photograph taken in May 1982 from the corner into which U8 points.

In this report we will focus on beamlines U9A, U9B, U11, U14, and U15, which are primarily the responsibility of the NSLS. These beamlines have been described in detail in references 1 and 2 which give fairly complete information on the hardware configuration and expected performance. We do not repeat this information here, but rather, concentrate on the activities of the last 12 months.

II. INSTALLATION AND COMMISSIONING

II.1 Alignment: General

For optical systems involving radiation of wavelength shorter than 1800 Å, alignment is always complicated by the need to operate in vacuum. When an electron storage ring source is used there are two further difficulties: first, the source point itself is inaccessible and second, access to locations having a direct line of sight to the source is restricted because of radiation hazards. We have constructed a system which produces an image of the source which coincides with a laser illuminated pinhole. The latter is located in a convenient, accessible place and simulates the synchrotron radiation (SR) source with laser light. The use of an image of the source is more accurate than methods that align a laser beam to the rays of SR using apertures.

The angular accuracy of the method is then given by the error in superimposing two small images divided by the path length. This can often be as small as a few arc seconds which could never be achieved with a system of apertures. In addition to solving the problem of access to the source, the technique also allows the use of auto-collimation techniques. We have found such techniques extremely useful in carrying out difficult alignment tasks involving aspherical grazing incidence reflectors. Beamlines U4, U7 and U14 utilize a soft x-ray plane grating monochromator (PGM) whose high resolving power is achieved only if the optics are properly positioned. For example, the parabolic collimating mirror for this instrument must be placed so that its focal point 10 m away coincides with the source within 1 mm radially. We describe below our apparatus for laser simulation of the source and our auto-collimation technique for aligning the PGM.

II.2 Optical System for Laser Simulation of the Source

The apparatus is shown in Fig. 3. It consists of a concave mirror M with holder and tilt stage, whose radius R is equal to its distance from the source, a beamsplitter B on a tilt stage, a laser L with an x-y translation and double tilt stage and a pinhole P. The pinhole is attached to the laser and produces a spherical wave source. Initially all the components are placed in rough position by conventional surveying techniques. Thus, B and M are placed on the theoretical beam line with M at a distance R from the source and B at any convenient location on MS. The laser/pinhole combination must then be placed at a distance R from the mirror approximately at beamline height and the laser tilts adjusted to fill B. B can then be tilted to fill M which is adjusted to return the beam to B and form an image near P.

The next step is to bring SR down the beamline. Assuming that B and M intercept the SR properly, there will be an image of S near the laser image. The laser spot is now moved toward the SR spot. This is accomplished by using the laser translate and tilt (in the same plane) together so that eventually the two spots are superimposed. Then both spots are shifted using the mirror tilt so that they lie on the pinhole. The mirror M is now auto-collimating both laser and SR light back to their sources and the laser is accurately simulating the SR source in both position and direction. No accurate setting of the orientation of the beam splitter or the direction BP is needed.

II.3 Auto-collimation Technique

For the soft x-ray PGM the beamline alignment can now proceed as follows. M is replaced by the monochromator which has a parabolic collimating mirror CM (Fig. 4). This mirror has a machined back surface which is perpendicular to the symmetry axis of the paraboloid of revolution. On this surface (surface A in Fig. 4) a plane mirror is pressed. This assembly is now positioned in roll, pitch, yaw and location to auto-collimate the laser spot back to the pinhole. If necessary, a check can also be made that the image of s is returned to the same pinhole. The beamline alignment is now complete.

In the case of U4, U7 and U14, R was 10 meters and the return beam could be made coincident within ~ 1 mm giving the necessary accuracy.

II.4 Beamline U9A

Beamline U9A is a lithium fluoride windowed beamline, built by the NSLS in collaboration with the Brookhaven Chemistry Department. It is to be used for studies of excited state lifetimes, photoconductivity, and UV circular dichroism. Its useful wavelength is 1050 - 12000 Å. The beamline monochromator is a medium (1 - 10 Å) resolution Seya-Namioka device, purchased from Acton Research Corporation. The experimental chamber is designed to be easily and rapidly convertible among experiments determining excited state lifetimes, by fluorescence, in gaseous and liquid hydrocarbons, atomic systems, photoconductivity in solutions of hydrocarbons in nonpolar solvents, and circular dichroism.

The beamline is controlled by a PDP 11/23 minicomputer, and data analysis is performed on the same computer. Complex calculations can be transferred to larger, remote computers as well.

First photoconductivity spectra were observed in late July 1982.

II.5 Beamline U9B

Beamline U9B supplies radiation to either of two low-energy spectrometers and was designed and built by NSLS in collaboration with the Brookhaven Biology department. The beam can be switched between the spectrometers by a mirror located in the UHV section of the vacuum system. An evacuable spectrometer is designed for experiments that exploit the high

intensity and continuous spectrum of synchrotron radiation, particularly in the far and vacuum ultraviolet ($\lambda > 130$ nm). This spectrometer has been installed and aligned. The first experiments which involve measurement of the circular dichroism of left and right handed duplex DNA, were performed in early August, 1982. A magnet for magnetic circular dichroism is on the experimental floor; it should be operable before the end of the year. The second spectrometer at U9B is designed to exploit the time structure of synchrotron radiation in the studies of the photophysics and photochemistry of biological molecules and studies of the motion of macromolecules on a nanosecond timescale. This station consists of a double (prism plus grating) monochromator positioned between the incident beam and the sample and a second monochromator between the sample and detector. Fluorescence lifetimes will be measured using the method of single photon counting. This non-vacuum spectrometer will be able to excite samples with wavelengths as short as 186 nm. A large sample compartment provides room for polarizers and other auxiliary equipment. All major components are onhand or on-order. The monochromators and sample chamber are in position and will begin operation in the next month or so.

II.6 Beamline U11

This beamline consists of a specially designed Wadsworth monochromator³ provided by NSLS and a large molecular beam experimental system constructed by the Brookhaven Chemistry Department. Both the monochromator and experimental system are in a working state and the monochromator is presently being installed and aligned. We expect to open it to SR in the next week or two and then the experimental system will be moved into position.

II.7 Beamline U14

Details of the alignment technique for the plane grating monochromator on the beamline have already been discussed in Section II.1. A schematic of the optical system for the PGM is shown in Fig. 5. The auto-collimation exercise using the collimating mirror has already been described. Figure 5 shows how the introduction of a plane parallel plate

permits auto-collimation to be performed in turn on each of the four focussing mirrors corresponding to the four ranges of the instrument.² All the optical components were installed in the instrument prior to its placement on the beamline, taking advantage of these techniques, using either a laser or a mercury lamp. Zero order scans were run in visible light to make a limited check on the image sizes for each range. These were diffraction limited to between 80-200 μ . Careful cleaning of the mechanism ensured that base pressures of $4 \cdot 10^{-10}$ T were achieved after alignment on the beamline and following a 48 hour bake in an oven, keeping the base flange at 65° C. The instrument is pumped by a 220 l/sec ion pump/TSP combination.

The experimental chamber has now been installed with an Al diode and outut scans have been run for all 4 ranges.

II.8 Beamline U15

This beamline consists of an unusual grazing incidence TGM with no entrance slit. The concept is similar to that of Madden and Ederer.⁴ The paramaters are, source/grating distance: 3.024 m, grating/exit slit distance: 6.061 m and included angle: 174.28°. A single lamina grating is used with density: 600 gr/mm, groove depth: 120 Å (aprox) ruled area 15 x 50 mm² and radii: 187 mm and 88 m (approx). The output spectrum has been measured⁵ using an aluminum photodiode and is shown in Fig. 6. From this and similar measurements we can infer a good deal of useful information:

1. The absolute photon output (obtained by using the photo-yield data of Day⁶ et al.) is very high and corresponds at 30 Å to a diffracting efficiency of 25% (+1 order). This is near the upper limit of what is possible which is: peak scalar diffracting efficiency = 40%, reflectance of gold at 30 Å = 58% giving 23% overall. However, we do not take this close agreement seriously in light of the large uncertainties in the photodiode calibration and storage ring current.

2. The shape of the output spectrum is in reasonable agreement with the calculation. The fall-off at long wavelength is due to a combination of blaze effects and the decline in collection angle.
3. The use of the 800 Å aluminum filter in front of the grating is intended to limit the contamination rate by reducing the photon flux in unwanted parts of the spectrum. One can see that it also has a very beneficial effect on the amount of stray light without significantly reducing the useful flux.
4. The various features in the spectrum which are labelled as due to the edges of the elements Al, Fe, O, Ca and C are all believed to be due to the photo diode. The respective processes involved in bringing this about could be, manufacture, machining, corrosion, washing and vacuum contamination.
5. The steepness of the edges gives a crude idea of the resolution of the system. In theory this should be determined by both the source size (low λ) and aberration properties (high λ). At the present time we can only say that the values of resolution determined in this way are consistent with our knowledge of the source size which appears to be dominant for most of the range.

In addition to the data of Fig. 6 the profile of the central image has been studied in some detail. Examination of the measured curves plus exact ray traces leads to the following tentative conclusions.

- a. The vertical σ of the source at low beam current is $200 \pm 50 \mu$ and this increases by a factor of from 2 to 4 at high current.
- b. The grating surface which is within 5 mm of the ends has poor surface figure (edge roll-off) and must be masked out to get a good image.
- c. Various low frequency oscillations in the image of the source become visible when the filtered zero order beam is viewed by eye using an x-ray to visible wavelength shifter.

Our observation of the performance of this beamline reinforces our expectation that it will be excellent for microscopy, EXAFS and other soft x-ray experiments requiring moderate resolution.

References

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5. The authors are grateful to J. Kirz, H. Rarback, J. Kenney and B-X. Yang of the State University of New York at Stony Brook for providing details of these measurements.
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Figure Captions

- Fig. 1. NSLS VUV Storage Ring at Brookhaven National Laboratory showing port numbering scheme and some first beamlines.
- Fig. 2. Photograph taken in May 1982 from the end y beamline U8 of the NSLS VUV Storage Ring at Brookhaven National Laboratory.
- Fig. 3. Plan view of components used to set up beamline. M = concave mirror, radius R; B = beam splitter; S = synchrotron radiation source; P = pinhole; L = laser.
- Fig. 4. Side view of auto-collimation scheme for the NSLS plane grating monochromator used on beamlines U4, U7 and U14. Beamsplitter B, pinhole P, and laser L collimating mirror: CM, plane mirror: P, synchrotron radiation source: S.
- Fig. 5. Schematic of the focussing scheme of the NSLS plane grating monochromator.
- Fig. 6. Output spectra for grazing incidence TGM on beamline U15 for a beam energy of 600 MeV. The absolute measurements were taken with a horizontal collection angle of 5 milliradians. The right hand scale refers to the open circles.

NATIONAL SYNCHROTRON LIGHT SOURCE/BROOKHAVEN NATIONAL LABORATORY

UV SCIENTIFIC PROGRAM

PORT AND AFFILIATION	EXPERIMENT	λ (Å)	MONOCHROMATOR
U 1. -			
U 2. NSLS DIAGNOSTICS			
U 3. -			
U 4. BELL LABS	A) SEXAFS/ARUPS/XPS B) ARUPS C) ARUPS/ABS/REFL.	12-1200 80-5000 400-6000	PGM TGM NIM
U 5. NSLS	FREE ELECTRON LASER		
U 6. IBM	LITHOGRAPHY	WHITE	
U 7. BNL/SUNY	ARUPS/XPS/SEXAFS GAS SOLIDS	15-1200	PGM
U 8. IBM	A) ARUPS B) ARUPS C) EXAFS/SEXAFS/MICR'TY.	18-2000 80-2500 8-100	TGM TGM FRESNEL ZONE PLATE
U 9. NSLS/BNL-CHEM. NSLS/BNL-BIO.	A) FLUORESCENCE LIFETIME B) DICHOISM/FLUORESCENCE	1050-120,000 1200-300,000	NIM NIM
U11. NSLS/BNL-CHEM.	GAS PHASE SPECTROSCOPY	300-2000	NIM
U12. U. OF PENNSYLVANIA	A) ARUPS B) ARUPS INFRA-RED VIBRA'TNL. SPECT.	15-100 80-2500 10 ³ -10 ⁶	TGM TGM NIM
U14. NSLS	A) ARUPS/XPS/SEXAFS	15-1200	PGM
U15. NSLS/SUNY	TGM MONOCHROMATOR/MICROSCOPE	12-50	TGM

UNASSIGNED:

U10, U13 & U16.

PGM = PLANE GRATING MONOCHROMATOR

TGM = TOROIDAL GRATING MONOCHROMATOR

NIM = NORMAL INCIDENCE MONOCHROMATOR

TABLE I

U14

U15

U11

U9A

R.F. CAVITY

U4

U9B

U8

U7