FIRST OPERATION OF AN EXTENDED RANGE GRASSHOPPER MONOCHROMATOR ON THE ALADDIN STORAGE RING

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First operation of a new extended range monochromator on the 1 GeV storage ring Aladdin is described. Curves are given of output flux as a function of photon energy for the 2 m and for the 5 m gratings as measured with an NBS diode. Relatively low background and flux up to 1500 eV is obtained using a 1200 line/mm 5 m holographic grating. Highly reproducible scans were obtained of the transmission of thin films including the carbon K and titanium L edges. This reproducibility and high throughput is in large part due to the small beam size and excellent stability of Aladdin.

1. Introduction

An ultrahigh vacuum beamline for the 1 GeV storage ring Aladdin was described at the Synchrotron Radiation Instrumentation Conference at Hamburg in 1982 [1]. The heart of this beamline is an extended range grasshopper (ERG) monochromator [2] which employs a 5 m as well as a 2 m grating in order to improve Rowland circle resolution at extremely short wavelengths up to 1500 eV photon energy. The optical design of the monochromator is similar to the original grasshopper [3] which employed fine entrance and exit slits on a Rowland circle in order to achieve high resolution independent of the source size in orbit.

The storage ring Aladdin is now in operation with stored electron beams increasing above 30 mA * * Note added in proof: A current of 106 mA at 1 GeV was achieved on January 8, 1986. 

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2. Optical design

Close coupling of the monochromator to the synchrotron source is achieved by the use of a first surface mirror which is almost a meter in length at a two degree grazing angle of incidence. At 2.35 m from the bending magnet source point this M₀ mirror (see fig. 1) will focus approximately 15 horizontal mrad of radiation through the exit slit of the monochromator.

As shown in fig. 1a, radiation is focussed in the vertical plane by mirror M₁, which is a 30 cm long bent ellipse located a fixed distance (52 cm) from the adjustable entrance slit S₁. A 1° angle of incidence is used, and a line image of the source point is focussed onto S₁ with approximately 7:1 demagnification. M₂S₂ is a mirror/slit combination [4] which keeps the radiation directed onto either of two gratings G₂ or G₃ with either 2 m or 5 m radius of curvature, respectively.

Unlike its predecessor [3] the ERG monochromator has no external or internal toggle mechanisms for tracking of the grating arm and slit mirror during scan. Instead, the separate motions of these elements are precisely coordinated with the motion of the linear air bearing by computer control. For this purpose stepping motor rotations are transferred into ultrahigh vacuum through bellows by means of microslides and connecting links which contain flexural hinges. Tests of the grating arm motion with an interferometer show that the required reproducibility can be achieved, and they also yielded the coefficients in polynomial expansions of the motion which can be used in the software to link the stepping motor count in microsteps (32 microsteps per half step) to the distance between entrance and exit slits L, the fundamental scan parameter of the instru-
Fig. 1. (a) Arrangement of optical elements in the ERG monochromator. The position shown is zero order for the 1200 lines/mm 5 m grating G₅ and -160 eV for the 2 m grating G₂. (b) Shows how a coarsely ruled 1 m grating G₁ can be mounted on the 2 m arm for long wave operation. In both (a) and (b), the radiation comes in from the collecting mirror M₀ at the right, which focusses in the horizontal plane.

ment. Motions of the flexural hinge parts can also be simulated by assuming connecting links with pivot points at the centers of the flexural hinges. In practice this seems to be quite adequate, and it is not necessary to use a bending beam calculation nor extensive interferometer tests.

The flexibility of software control allows one to change important parameters, for example, the diameter of the Rowland circle. Thus scanning of the ERG can be accomplished with either of two grating arms, one for the 2 m, the other for the 5 m grating. Both gratings are normally 1200 lines/mm. It is also possible to mount a third 3.7 m grating on the 5 m arm. If this grating has a 600 lines/m ruling density it can be used from ~120 eV to almost zero order. One has only to position the 2 m arm out of the way and change the programming.

It is also possible to extend the long wavelength range of the ERG monochromator by mounting a coarsely ruled 1 m grating on the 2 m arm. For this purpose, the grating is tilted 2° in its mount so that a grazing incidence angle of 4° can be used. This allows for a larger blaze angle (4°) for better efficiency at long wavelengths. When this is done and the programming changed, the beam emerges from the fixed exit slit of the monochromator at 4° above the horizontal instead of the usual 2°. This angle is constant during scan and a small flat mirror just beyond the exit slit can be used to redirect the exit beam toward the refocussing mirror. Although this long wavelength option was not employed in the present installation on Aladdin, it could provide for scanning from 6 to 160 eV using a 150 lines/mm grating. The limiting factor at the higher energy is a low relative band width.

The expected performance of the ERG as coupled to Aladdin was determined by use of a ray tracing program. Details are to be found in ref. [1]. Recent experience shows that this performance is close to being met.

3. Performance as installed on Aladdin

As of July 1985, the new storage ring Aladdin operates routinely at 800 MeV with electron beam currents up to about 30 mA. Higher currents have been obtained at injection (100 MeV). The difficulties associated with ion trapping are being overcome by installation of clearing electrodes so that the stored currents at energy are steadily improving.

An important parameter of a new low emittance storage ring such as Aladdin is the size and stability of the electron beam in orbit. This information can be obtained using high quality optical imaging of the synchrotron radiation. It can also be obtained using the X-ray optics of the monochromator. Fig. 2 of ref. [1] shows a side view of the monochromator along with the
The accurate pivoting arrangement of the $M_1$ mirror box. This allows precise adjustment of the focussed image point onto the entrance slits. Measurements were made of the throughput of the monochromator versus tilt of $M_1$ as measured by an electronic dial guage. These showed that the focussed image at the entrance slit $S_1$ has a fwhm of 75 $\mu$m. Moreover, for a given setting, the throughput is highly stable and does not have a strong dependence on beam current. Little or no adjustment of the $M_1$ position has to be made from one injection to another. Referring back to the source point, an upper limit can be placed on the height of the beam in orbit of $\sigma_z = 200 \mu$m.

The monochromator and $M_0$ chamber was put into place on the beamline with the aid of visible synchrotron radiation coming through the windows. Following adjustment, a visible zero order beam width of 1.5 mm was observed at the exit slit. Exit slits of 10, 50 and 200 $\mu$m (formed by photolithography) could be moved into place. The entrance slit was continuously adjustable.

In the present experiments a selection of thin films could be rotated into place just beyond the exit slit. Beyond that a microchannel plate detector capable of photon counting was located. This detector could be moved out of the way so that the exit flux could also be measured with a National Bureau of Standards aluminum oxide diode. The diode currents were observed with a microammeter and an analog-to-frequency converter. A baffle with a carefully positioned aperture was placed in front of the exit slit to exclude zero order and stray light from the sample chamber and detector region.

Fig. 2a shows a scan of the NBS diode current as a function of photon energy using a 5 m 1200 lines/mm holographic grating [5], 10 $\mu$m slits and the storage ring operating at $\sim 4$ mA. The carbon K edge can be seen just below 300 eV, at which point the observed current corresponds to $\sim 2 \times 10^8$ photons/s. The large spectral feature beginning at 550 eV is due to the oxygen K edge and increased yield of aluminum oxide diode. Distinct EXAFS can be seen above this threshold. Notice that flux can be seen out to about 1500 eV, above which a very low stray light extends toward zero order.

The zero order flux was also observed and found to have a fwhm of 0.08 $\AA$. This is somewhat wider than expected but the focus of the instrument is still under investigation. A most important parameter is the figure and radius of curvature of the grating. A Focault test must be run to accurately ascertain the radius and figure, especially of the 5 m grating. The output of the instrument was measured using 10 $\mu$m slits. On the other hand, diode currents were observed to increase almost 100 times as the slits were opened (approaching microamperes at zero order).

Fig. 2b shows a scan of the NBS diode current as a function of photon energy using a 2 m 1200 lines/mm holographic grating [5], 10 $\mu$m slits and the storage ring operating at $\sim 4$ mA. The carbon K edge can be seen just below 300 eV, at which point the observed current corresponds to $\sim 2 \times 10^8$ photons/s. The large spectral feature beginning at 550 eV is due to the oxygen K edge and increased yield of aluminum oxide diode. Distinct EXAFS can be seen above this threshold. Notice that flux can be seen out to about 1500 eV, above which a very low stray light extends toward zero order.

Fig. 3. Transmission of a Ti film near the Ti L$_{2,3}$ absorption edge.
grating with a 10 μm slits. Again the carbon K edge can be seen around 300 eV. In fact this energy was used for calibration in the programming since the 2 and 5 m ranges overlap. Just below the carbon edge the oxygen K structure can again be seen in second order. Toward lower energies the aluminum L edge is observable at ~73 eV.

Transmission scans of a number of thin films were observed in order to test the reproducibility which was found to be excellent. As an example, fig. 3 shows the recorded transmission I of a thin titanium film in the vicinity of the L₂,₃ edge at 460 eV (a small energy correction has not been made). Notice that the edge has a width less than ~0.9 eV. Fig. 4a shows the optical density of the film log I₀/I obtained by referring to a separate I₀ scan. In fig. 4b we show the separated L₃ and L₂ components obtained by numerically deconvoluting with a 2:1 weighting factor and a shift of 6.1 eV. This value of spin-orbit splitting is in good agreement with photoemission data [6] but disagrees with earlier lower resolution absorption data [7].

4. Summary

The first use of an ERG monochromator on the storage ring Aladdin is reported. The various scan motions are coordinated with use of an LSI-11 computer and microprocessor control system. Excellent reproducibility and stability were obtained.

A flux of ~2×10⁸ photons/s was obtained at the K edge of carbon with 10 μm slits and a beam current of 4 mA. This value can be compared with a theoretical output flux of ~1.5×10¹⁰ photon/s for 100 mA given in table 2 of ref. [1]. When a correction is made for the increased current and for the actual observed image size at S₁ our observed number becomes 1.7×10¹⁰, which is in good agreement.

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