

## The LNLS soft X-ray spectroscopy beamline

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The soft X-ray spectroscopy beamline installed at a bending-magnet source at the LNLS is described. The optics are designed to cover energies from 800 to 4000 eV with good efficiency. The focusing element is a gold-coated toroidal mirror with an angle of incidence of 17 mrad. The UHV double-crystal monochromator has three pairs of crystals, Si (111), InSb (111) and beryl (10 $\bar{1}$ 0), that can be selected by a sliding movement. The UHV workstation is equipped with an ion gun, an electron gun, an electron analyser, LEED optics, an open channeltron and a photodiode array. This beamline is intended for photoemission, photoabsorption, reflectivity and dichroism experiments.

**Keywords:** soft X-rays; spectroscopy; beamline optics.

### 1. Introduction

The LNLS synchrotron radiation source consists of a 1.37 GeV storage ring and a 120 MeV linear accelerator, for injection at low energy. The storage ring is a third-generation light source with a critical energy of 2.08 keV. The lattice is a sixfold-symmetry double-bend Chasman–Green achromat lattice with twelve 30° 1.4 T rectangular bending magnets. The achromats connect six 2.8 m-long dispersion-free straight sections, four of which could be used for insertion devices. The natural emittance is 100 nm rad and the frequency of revolution is 3.2 MHz for this 93.2 m-long machine (Rodrigues *et al.*, 1997). The storage ring has been commissioned and attained the target parameters of 100 mA at 1.37 GeV. Fig. 1 displays the photon flux produced by the bending-magnet source. The average lifetime obtained so far is about 5 h and a lifetime of 10 h is expected to be reached by the end of 1997 (Craievich & Rodrigues, 1997).

### 2. Beamline description

The SXS beamline is installed at a bending-magnet source of the LNLS storage ring. This beamline is intended for soft X-ray spectroscopy experiments in the energy range from 800 up to 4000 eV. The design and test performance of all the critical elements of the beamline have been performed entirely at LNLS. The main components of the beamline are (see Fig. 2): (i) the bending-magnet source, (ii) the security front-end, (iii) the gold-coated toroidal mirror, (iv) the double-crystal monochromator, and (v) the experimental workstation. There are, in addition, two sets of slits and a set of filters containing 0.75 and 2.4  $\mu$ m

aluminium filters. The beamline has no windows and its vacuum has to be compatible with that of the storage ring and front end, *i.e.* below 10<sup>-8</sup> mbar.

The horizontal and vertical dimensions (FWHM) of the source are 830 and 165  $\mu$ m, respectively. The vertical divergence is 370  $\mu$ rad at the critical energy, limited by 1/ $\gamma$ . The maximum horizontal acceptance, defined by the mask in the front end, is 12 mrad. This limit was imposed by the horizontal acceptance of the focusing mirror.

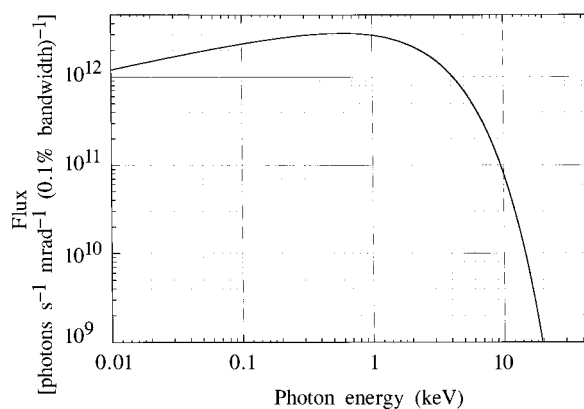
### 3. Mirror

A gold-coated toroidal mirror (340  $\times$  100  $\times$  40 mm) is installed at 6.5 m from the source, half-way between the source and the sample position. The angle of incidence was fixed at 17 mrad, so that the reflectivity is kept within reasonable values in the energy range of the beamline (see Fig. 3). Once the optical parameters were defined ( $R_{\text{mer}} = 372441$  mm,  $R_{\text{sag}} = 113$  mm), simulations with the *SHADOW* code (Welnak *et al.*, 1992) were carried out. A figure of 3.2  $\times$  1.5 mm at the sample was predicted by the simulations.

The toroidal mirror is placed inside a UHV chamber maintained at a pressure below 5  $\times$  10<sup>-9</sup> mbar by a 120 l s<sup>-1</sup> ion pump. This chamber has four vertical translation stages with stepping motors, located outside, for positioning and alignment of the mirror. Height, incidence and tilt angle can be adjusted with a precision of 0.5  $\mu$ m, 1.5  $\mu$ rad and 6  $\mu$ rad, respectively. The yaw angle is adjusted externally within 0.5 mrad. Currently, its fine alignment is performed using the synchrotron beam. The spot size was measured by the total electron yield from a screen scanned in position with 0.1 mm steps; the figure obtained at the sample position (FWHM) was 0.2  $\times$  0.9 mm (Fig. 4). This spot size is smaller than that predicted by the *SHADOW* simulations because the slope error and roughness of the mirror turn out to be better than expected (r.m.s. slope error: <2.14' meridionally, <5.76' sagittally; r.m.s. roughness: <3.3 Å). The expected intensity of photons within the spot size is 3  $\times$  10<sup>13</sup> photons s<sup>-1</sup>, in a bandpass of 0.1% and with the storage ring running at 100 mA.

### 4. Monochromator

The UHV double-crystal monochromator has three pairs of crystals: Si (111), InSb (111) and beryl (10 $\bar{1}$ 0), that can be selected by a sliding movement. This is a big advantage because



**Figure 1**  
Photon flux from the bending magnets of the LNLS storage ring.

there is no need to break the ultra-high-vacuum of the monochromator chamber to change crystals. The photon energy covered by the monochromator ranges from 800 to 4000 eV. The rotation of the goniometer is achieved by a single high-precision translation stage connected to a drum by a thin steel wire. The translation stage, with  $0.5\ \mu\text{m}$  per step along with a drum of 200 mm in diameter, produces an angular resolution of  $5\ \mu\text{rad}$  per step, which is enough for the required application in soft X-ray spectroscopy. In principle, the goniometer can cover the range from  $0$  up to  $90^\circ$ . However, the useful angular range, due to limitations in the crystal dimensions, starts around  $10^\circ$  and goes up to  $80^\circ$ . A complete description of the double-crystal monochromators is given in previous a paper (Tolentino *et al.*, 1995).

In the double-crystal monochromator, the fine adjustment of the parallelism between the crystals is performed by a solenoid and a small permanent magnet with an accuracy of better than  $0.1$  arcsec. This can be used to remove harmonic contamination by detuning and to measure the rocking curves of the crystals.

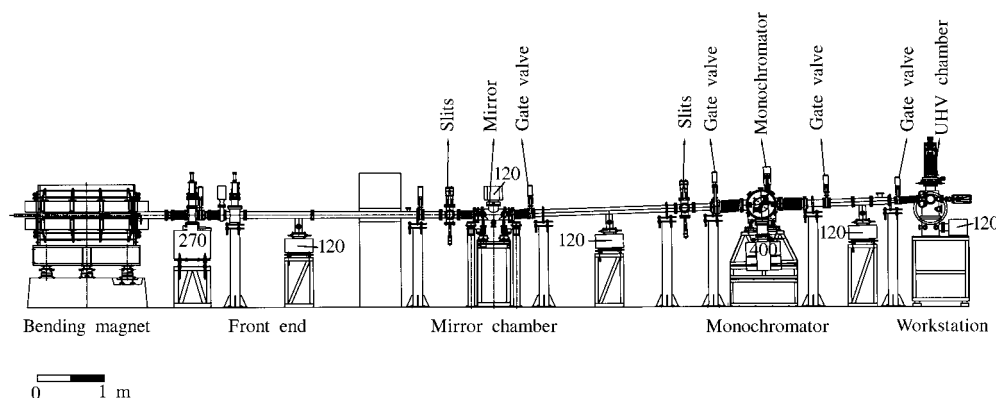
The monochromator was initially installed in a beamline with a Be window for preliminary alignment and characterization. This was carried out in the photon-energy range from 3000 up to 8000 eV. Fig. 5 shows the results for the width of the Si, InSb and beryl rocking curves taken at different energies. The first two crystals are perfect for X-ray optics and the widths are in agreement with the dynamical theory of X-rays. The resolving power obtained with these crystals is of the order of 5000 or

better. From the rocking-curve width and the peak intensities, the measured photon flux delivered by the InSb (111) crystals is about four times higher than that of Si (111). For many applications in the energy range 2000–4000 eV, the energy resolution is not very demanding and the InSb crystals will be better suited.

The beryl is a natural crystal that is very difficult to find in good quality and presents a high degree of mosaicity. Due to the absorption by the windows and limited Bragg angle, the rocking curves of beryl ( $10\bar{1}0$ ) were measured in a limited range. The large rocking-curve width may come from the misorientation of the different crystallites. Working with a small beam ( $1 \times 1\ \text{mm}$ ) it is possible to find a good region of the crystal and the width is reduced. Nevertheless, in normal conditions, the width of the reflection and resolution are limited by this mosaicity. The beryl crystal will be used in the 800–1600 eV region where the resolving power is limited to 3000.

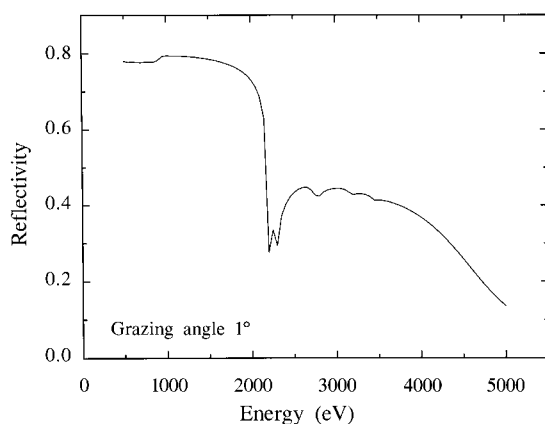
## 5. Workstation

The SXS workstation is intended for photoemission, X-ray absorption, reflectivity and dichroism experiments. It is equipped with an ion gun, an electron gun, an electron analyser, LEED optics, an open channeltron and a photodiode array. The photoemission experiments can be carried out using an hemispherical electrostatic electron-energy analyser. The X-ray



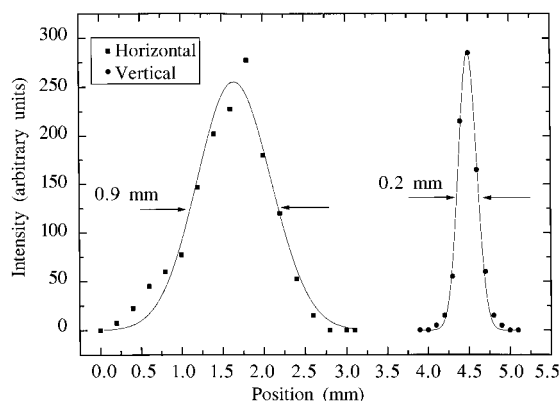
**Figure 2**

View of the SXS beamline: (i) the bending-magnet source, (ii) the front-end, (iii) the mirror, (iv) the monochromator and (v) the workstation. There are two sets of slits and no windows along the beamline.



**Figure 3**

Gold-coated mirror reflectivity at a grazing-incidence angle of  $17\ \text{mrad}$ .



**Figure 4**

Vertical and horizontal beam profiles at the sample position. The spot size was measured using the total electron yield from a screen scanned through the focus with a  $0.1\ \text{mm}$  step.

absorption spectra are usually measured in the total-electron-yield mode using the open channeltron. The reflectivity of the samples can be measured at grazing incidence using the photodiode array. Linear dichroism effects can be obtained using linearly polarized light from the orbit plane, and circular dichroism effects using elliptically polarized light from above (or below) the orbit plane.

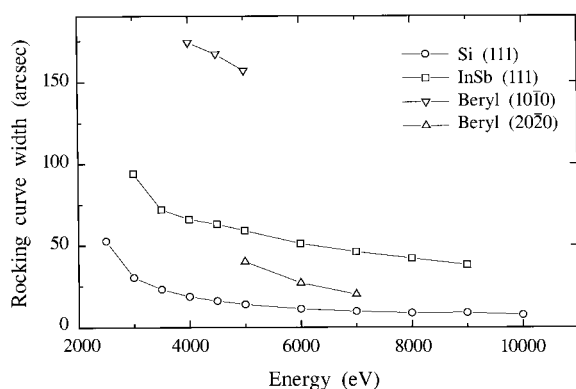
The UHV chamber has three levels. The lower level is dedicated to vacuum components; there is a  $400\text{ l s}^{-1}$  ion pump, a  $220\text{ l s}^{-1}$  turbo-molecular pump, a pre-vacuum valve and a vacuum gauge. The intermediate level is dedicated to sample preparation; it can have up to three evaporators, as well as an ion gun and a diamond file for cleaning purposes. The upper level is dedicated to the characterization of the samples; there is an electron energy analyser, LEED optics, an electron gun and a conventional X-ray source. The samples are introduced into the chamber through the manipulator at the top. This apparatus has

been used in conventional photoemission experiments and its performance is comparable to that of similar equipment.

The high-precision  $XYZ-\theta$  manipulator has several feed-throughs for electrical and thermocouple connections. The temperature of the sample can be controlled in the range 80–600 K using a liquid-nitrogen cryostat and an halogen lamp. Even higher temperatures can be attained by flashing the sample with a high-energy electron beam. Ferromagnetic samples can be magnetized using a pulsed high-current horseshoe electromagnet. Gases can be admitted in the UHV and adsorbed on the surface of the samples through a leak valve. Monolayers and multilayers can be grown on the surface of the samples using up to three different Knudsen-cell evaporators.

## 6. Conclusions

The SXS beamline of LNLS has been installed at a bending-magnet source and its commissioning is underway. The overall performance of the components is very satisfactory and comparable to that of similar existing apparatus.



**Figure 5**  
Rocking-curve width for the three pairs of crystals.

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