The SEXTANTS beamline at SOLEIL: a new facility for elastic, inelastic and coherent scattering of soft X-rays

Maurizio Sacchi, N. Jaouen, H. Popescu, R. Gaudemer, J. M. Tonnerre, S. G. Chiuzbaian, C. F. Hague, A. Delmotte, J. M. Dubuisson, G. Cauchon, et al.

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M Sacchi [1,2], N Jaouen[1], H Popescu[1], R Gaudemer[1], JM Tonnerre[3], SG Chiuzbaian[4], CF Hague[4], A Delmotte[1], JM Dubuisson[1], G Cauchon[1], B Lagarde[1] and F Polack[1]

[1] Synchrotron SOLEIL, Saint-Aubin, BP 48, 91192 Gif-sur-Yvette, France
[2] INSP, UMR 7855, CNRS-UPMC, 4 Pl. Jussieu, 75005 Paris, France
[3] Institut Néel, CNRS and Université J. Fourier, BP 166, 38042 Grenoble, France
[4] LCP-MR, UMR 7614, CNRS-UPMC, 11 rue P. et M. Curie, 75005 Paris, France

maurizio.sacchi@synchrotron-soleil.fr

Abstract. SEXTANTS is a new SOLEIL beamline dedicated to soft X-ray scattering techniques. The beamline, covering the 50-1700 eV energy range, features two Apple-II undulators for polarization control and a fixed-deviation monochromator. Two branch-lines host three end-stations for elastic, inelastic and coherent scattering experiments.

1. Introduction

SEXTANTS is a new beamline at SOLEIL synchrotron covering the 50-1700 eV energy range. The main scientific purpose is to investigate electronic and magnetic properties of solids using three scattering techniques, namely inelastic, magnetic, and coherent resonant x-ray scattering, including x-ray holographic imaging. These are all element selective photon-in–photon-out techniques with magnetic sensitivity and variable probing depths. In the following, we will present briefly the main characteristics of the SEXTANTS beamline, making reference to the schematic layout of Fig. 1.

2. Beamline layout

2.1. Source

The beamline features two Apple-II undulators of 44 mm and 80 mm period, providing full polarization control over the whole 50-1700 eV energy range [1]. The two 1.6 m long modules are installed in the ID-14M medium-length section, one at its center (HU44), the other 1.8 m upstream (HU80) This configuration leaves the possibility of installing a third undulator module in the future.

2.2. M1-A/B mirrors

The first optical element of the beamline is a pair of horizontally deviating mirrors (M1-A/B) working at 4° deviation [2]. Both mirrors are water-cooled using a closed-circuit thermostatic bath, and are installed in an aluminium-alloy UHV vessel with all the motors placed outside the chamber [3]. The purpose is to minimize the strong and rapid carbon contamination of first optical elements that has previously been observed on similar SOLEIL beamlines [4]. M1-A is a Pt-coated SiC plane mirror whose primary function is to absorb up to 90% of the thermal load from the undulator. At 15.5 mm undulator gap, linear polarization mode and full filling of the ring, maximum absorbed power is

~400 W, with a central power density of ~0.6 Wmm^{-2}. M1-A, placed 20 m from the center of the straight section, collects a maximum solid angle of 0.4×0.4 $mrad^2$. M1-B is an Ir-coated Si spherical mirror (224 m radius), focusing the beam horizontally at the slit placed after M2 (see Fig. 1). The M1-A/B pair has two additional functions: i) fine adjustment of the deviation angle in order to account for different source positions (HU44 or HU80); ii) satisfy radiation safety requirements by displacing the beamline axis laterally with respect to the source axis.

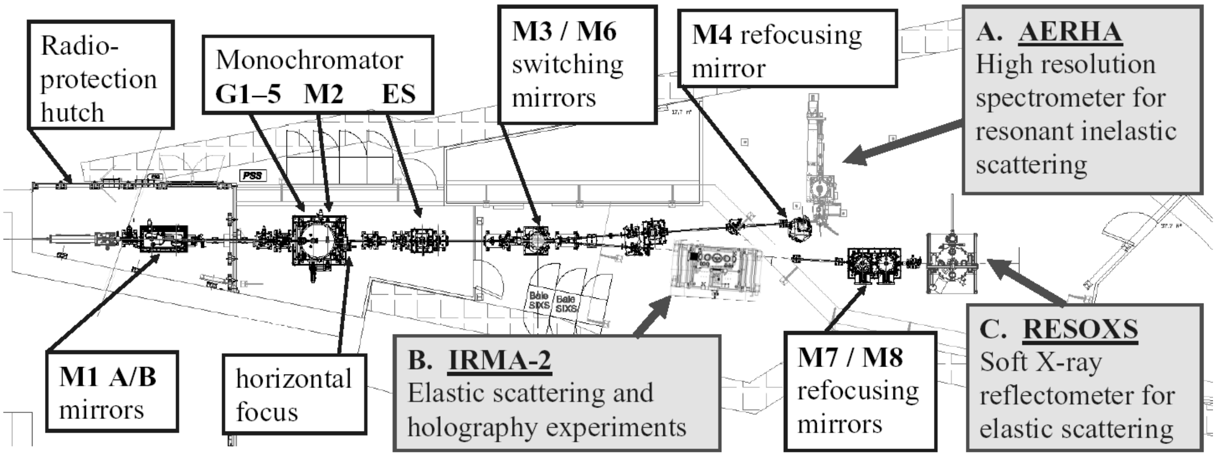

Figure 1. SEXTANTS beamline layout. Main optical elements and the three working positions A, B and C are indicated.

2.3. Monochromator

The fixed-deviation (5°) monochromator [5] comprises five interchangeable VLS gratings (G1-G5) and one spherical mirror (M2, 116 m radius). The central line density of the gratings, in lines/mm, is 120(G1), 225(G2), 450(G3), 900(G4) and 1500(G5). With the exception of G5, gratings are of the variable-groove-depth (VGD) type [6], allowing for a trade-off between spectral purity and efficiency. Calculated efficiency is >20% up to 700 eV and >15% up to 1500 eV. All gratings are mounted on the same base-plate for rotation (energy selection) and translation (grating and groove-depth selection). The rotation is measured using the graduations of a full-circle encoder with two read-heads. M2 focuses the radiation dispersed by the grating to the vertically occulting exit slit ES, placed 2.843 m downstream. For stability, the monochoromator hutch is thermalized to better than 0.1°C and all gratings and M2 are water-cooled via a closed-circuit thermostatic bath. In addition to the main elements G, M2 and ES, the monochromator ensemble features a 4-jaw assembly for defining the illuminated grating area and a vertical-blade-slit defining the horizontal source size for the optical elements downstream.

2.4. M3/M6 switching mirrors

The monochromatic beam is directed alternately along the two branches of the beamline by using two horizontally deviating toroidal mirrors [2]. M3 (r=122 mm; R=202 m) feeds the inelastic scattering branch, focusing the beam horizontally at working point A. M6 (r=144 mm; R=157 m) focuses the beam horizontally and vertically at working point B of the elastic scattering branch (see Fig. 1). Both M3/M6 mirrors are mounted on the same hexapod device [7]. When one mirror is selected as active in the control software, the hexapod movements refer automatically to its coordinate system, providing total control of its alignment through pure rotation and translation movements.

2.5. M4 refocusing mirror

Following the M3 switching mirror, vertical focusing at working point A is obtained via the upward deviating elliptical-cylindrical mirror M4 (R=26m, 4° deviation) [8]. Since a very small vertical size is required, the mirror produces a large demagnification (9:1) and features very low slope errors for its shape [9]. The M4 mirror chamber is mounted on a hexapod device for alignment [7].

2.6. M7/M8 refocusing mirrors

After the intermediate focal point B, the beam reaches a pair of refocusing mirrors in Kirkpatrick-Baez configuration (M7, 4° horizontal deviation, and M8, 2° upward deviation). Both are plane silica mirrors [10] mounted on mechanical benders [11] driven by in-vacuum stepper motors. The range of bending radii makes it possible to displace the focal position of working point C between 2 m and 4 m from the M8 mirror position, allowing for a trade-off between spot-size and divergence.

3. Monochromator performance

The beamline design was optimized to have a resolving power R>10000 up to 1000 eV, for a 10-20 µm opening of the ES. In general, optimization refers to the energy range 70-1300 eV. Below 70 eV, some 10-20% of the flux is lost due to increased source divergence. Above 1300 eV, the resolving power diminishes (R≈5000 up to 1700 eV) and the HU44 undulator must be used in third harmonic. Gas-phase absorption spectra confirmed the expected resolution performance. The highest energy that we tested up to now corresponds to the Ne-1s absorption at 867 eV. An example is shown in Fig. 2a, using the G5 grating and 5 µm exit slits. A Voigt fit, assuming a 252 meV Lorentzian broadening w_L [12], gives a Gaussian broadening w_G of 31 meV and a resolving power R≈28000 (the large difference between w_L and w_G implies large uncertainties on the latter). Fig. 2b summarizes the R estimates obtained by N-1s and Ne-1s absorption measurements, using different gratings and diffraction orders. Although G4 (900 l/mm) seems to perform slightly worse than expected, the beamline attains its original goal of R=10000 up to 1000 eV. The behaviour of G5 at 867 eV suggests that R>10000 can be attained up to 1300 eV.

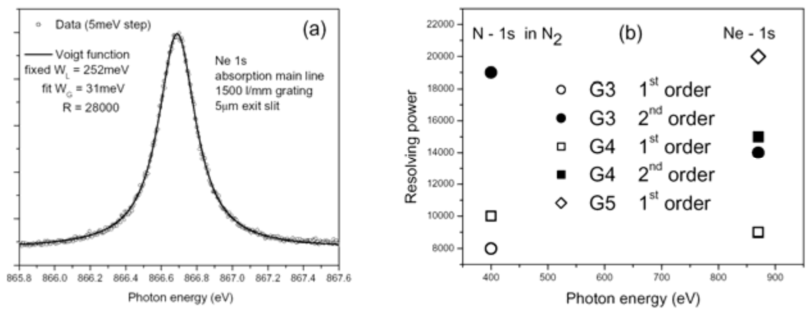

Figure 2.
(a) Ne-1s absorption using G5 grating and 5 µm slits.
(b) Summary of R values obtained by N-1s and Ne-1s absorption measurements.

Flux has been measured using a calibrated photodiode [13]. To compare with calculations, data were reduced to take into account variable resolving power as a function of energy. The design goal of 10^{13} ph.s^{-1}/0.1%BW is surpassed between 50 eV and 1000 eV, with a maximum of 10^{14} ph.s^{-1}/0.1%BW around 100 eV. 10^{12} ph.s^{-1}/0.1%BW are obtained up to 1500 eV.

4. Working positions

4.1 Inelastic scattering branch, working position A

Working position A hosts permanently the high resolution spectrometer AERHA, whose characteristics and performance will be detailed elsewhere [14]. The vertical spot-size at A is a critical parameter for attaining nominal performance of the vertically-dispersing spectrometer. Using both knife-edge scans and measurements of the intensity through a narrow slit, the best value of the vertical FWHM at A was measured to be 2.9 µm.

4.2 Elastic scattering branch, working position B

Working position B is defined by the focal point of the M6 switching mirror. Using knife-edges driven by piezoelectric motors, the spot-size has been determined to be 80 µm×50 µm, h×v, in excellent agreement with design values. Position B can host either the IRMA-2 chamber [15], designed for reflectivity and coherent scattering experiments [16], or external equipment brought-in by users.

4.3 Elastic scattering branch, working position C

Working position C is defined by the M7/M8 bendable mirrors. It hosts the reflectometer RESOXS [17], equipped for high-field (2 kOe) low-temperature (12K) experiments. External equipment can also be installed, if needed. The spot-size at 2.2 m from M8 has been characterized using a 2D imager (one pixel of the camera corresponds to 0.11 µm). Closing the beamline slits completely (Fig. 3, left panel), we estimated the contribution to the spot-size coming from slope errors and aberrations of the three mirrors (M6, M7 and M8) forming the image at C. The measured h×v FWHM was 8.4 µm × 3.4 µm. When using 40 µm × 10 µm slits, we measured a FWHM of 17.3 µm × 7.4 µm, in excellent agreement with calculated values (right panel).

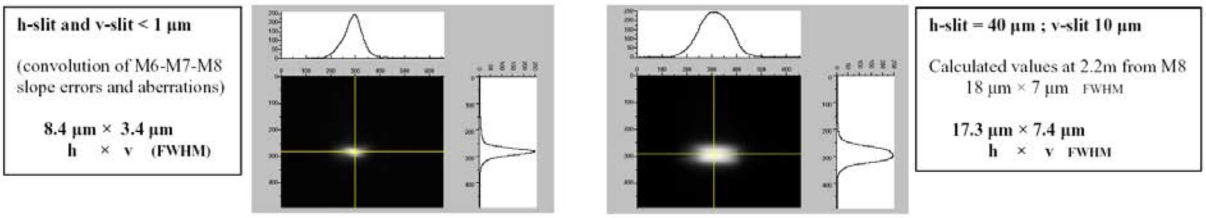

Figure 3. Images of the focal spot at working position C (2.2m behind M8). Left panel: slit apertures <1 µm^2. Right panel: slit apertures 40 µm × 10 µm (h×v); calculated values are given for comparison.

5. Conclusion

SEXTANTS is the Soleil beamline dedicated to polarized soft X-ray scattering experiments. It covers the 50 eV-1000 eV range with a resolving power that exceeds 10^4 and a flux at the sample that ranges from 1×10^{14} ph./s/0.1%bw at 100 eV to 2×10^{13} ph./s/0.1%bw at 1000 eV. The energy range up to 1700 eV can be covered with reduced performance. The SEXTANTS beamline was opened to external users in March 2011.

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