Experiment-led precision optical design and mechanics for beamline optimization

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Advanced mirror and bending technology combined with systematic measuring enables improved performance of synchrotron beamlines.

The Alba Synchrotron Light Facility is a scientific research complex on the outskirts of Barcelona in Spain. It consists of an electron accelerator ring with a perimeter of 265m, a nominal electron energy of 3GeV, and a horizontal emittance of 4.5nm·rad. This constitutes a high-brilliance source of light that scientists across the fields of chemistry, physics, and biology can use to gather information about the structural and chemical properties of materials at the molecular level (see Figure 1). The facility has capacity for 31 beamlines, fed either by bending magnets or insertion devices. These bring the light to end-stations where research experiments are carried out. For this to work, high-quality optical components and high-performing mechanical systems are installed at the beamlines. Optical layouts must also match the properties of the light source with the performance required by individual experiments.

The first phase of the facility consists of seven beamlines, which cover a variety of experimental techniques, including spectroscopy, microscopy, and diffraction. The experimental stations use different photon energy ranges, spot sizes, and spectral resolutions. These parameters are taken into account during the design phase to determine the optimal source type (insertion device or bending magnet) and the best-suited optical design, for instance, whether wavelength selection should be performed using gratings or crystals.

In most cases, optical performance could be achieved by making small modifications to standard optical layouts. However, as we have noted, practical considerations actually determine Alba’s optical layouts, for instance, misalignment tolerance of optics, motion simplicity for energy scans, or robustness to source drifts. Each of the Alba facility’s three soft x-ray beamlines uses a different monochromator concept, that is, varying combinations of mirrors and gratings or crystals used to select a specific wavelength band from the broadband spectrum of the light source (see Figure 2).

The photoemission spectromicroscopy beamline (BL24-Circe) requires a micron-sized spot at the sample position to correspond with the analyzing instrument’s small field of view. For that reason, we selected a classical plane grating monochromator, which uses a toroidal mirror to collimate, or make parallel, the beam that impinges on the grating. This allows for good reduction in size of the source. But more importantly, decoupling focusing from the grating diffraction makes it possible to have a fixed-exit slit position for the whole energy range, enabling a fixed geometry for the refocusing optics and simplifying beamline operation.

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The same monochromator concept could have provided the spectral resolution and photon flux required by the BL29-Boreas beamline, used for x-ray magnetic circular dichroism and resonant scattering. Here, however, we chose to use a grazing incidence Monk-Gillieson monochromator, because it has an entrance slit that ensures decoupling of the photon energy calibration from potential source drifts and allows energy scanning by rotating the grating only.\(^5\)

We also chose a different layout for the soft x-ray full-field microscopy beamline, named BL09-Mistral.\(^6\) This beamline is fed by a bending magnet, and it requires maximizing angular acceptance to collect as many photons as possible while providing constant angular magnification at the exit slit, which is a requirement for the end-station microscope to reach its optimal resolution. Because vertical acceptance of the beamline is normally limited by the length of the grating, we placed it very near an entrance slit. We used a varied line density grating version of the Petersen monochromator. Angular magnification in this device is determined by the fix-focus constant \(c_{ff}\) as defined previously,\(^7\) but the VLS (variable line spacing) version makes it possible to keep the beam focused at the exit slit, independently of the value of \(c_{ff}\).\(^8\)

To fully exploit the capabilities of the photon sources—in addition to experiment-oriented optical design—we collated the mechanical performance specification and metrology of positioning and scanning systems. To do this, we collaborated with some of our suppliers, and have supported design modifications based on finite element calculations on vibrational, thermal, or fluid dynamics aspects. In addition, the mechanical performance of all the beamlines’ critical components has been characterized using interferometer metrology. Techniques and data analysis codes have also been developed for this purpose, including drift estimation and vibration analysis (see Figure 3).

When it comes to the optical components, Alba’s beamlines benefit from the latest advances in mirror figuring (shaping) and bending technology, which applies a mechanical deformation to set the mirror figure. Most of the mirrors we use have slope errors below 0.5\(\mu\)rad. To this end, the facility’s optics

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*Figure 2. Side-view optical layouts of Alba’s three soft x-ray monochromators: (a) BL24-Circe; (b) BL29-Boreas; (c) BL09-Mistral. VLS: Variable line spacing.*

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metrology laboratory is equipped with a nanometer optical measurement machine: a state-of-the-art instrument for measuring optical surfaces. All the optical components at the facility have been characterized in this lab, and in some cases, the shape of the mirrors has been optimized. The most significant example of this is the focusing mirrors of the macromolecular crystallography beamline, for which the residual slope error was reduced to 80 and 55nrad rms, for a 600 and 300mm-long mirror, respectively.

In summary, the beamlines at the Alba Synchrotron Light Facility have been designed not only to fulfill optical performance requirements but also to cope with the practical aspects

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of the different experimental techniques. This has led to a variety of optical layouts. In addition, a systematic metrology program, and collaboration with suppliers, has allowed us to reach excellent mechanical and optical performance, improving the technical capabilities of our experimental stations. For the future, Alba plans to increase the number of beamlines at the facility. These new experimental stations will determine the specific optical layouts, but they will benefit from new developments in mirror technology and precision mechanics.

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References