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The multicrystal monochromators of the TROIKA beamline at ESRF

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A multicrystal UHV monochromator equipped with up to four different monochromator crystals, which can be exchanged *in situ*, is described. The monochromator is designed as a transmission monochromator in horizontal scattering geometry allowing the 'quasi-white' beam, after transmission through X-ray-transparent diamond or beryllium monochromator crystals, to be utilized in independent downstream stations.

Keywords: multicrystal UHV monochromators; diamond monochromators; beam multiplexing.

1. Introduction

The TROIKA beamline at ESRF provides high-brilliance X-ray beams from a common undulator source simultaneously to three experimental stations (Grübel *et al.*, 1994). This is achieved with the help of X-ray-transparent diamond or beryllium monochromators that allow the non-reflected beam to be transmitted into downstream experimental stations (Als-Nielsen, Freund, Grübel *et al.*, 1994). The multipurpose character of these stations necessitates maximum flexibility in terms of resolution, energy tunability and flux. This goal has previously been achieved by exchanging the monochromator crystals, necessitating frequent access to the monochromator vacuum system and time-consuming alignment procedures. We describe here a multicrystal UHV monochromator operating with up to four different monochromator crystals that can be exchanged *in situ*. The device allows adjustment of the energy resolution and the available flux during an ongoing experiment. The monochromator is designed as a single-bounce transmission monochromator in horizontal scattering geometry, permitting scattering angles (2θ) from 15° to 80° relative to the forward direction and tilt angles between +5° (up) and −15° (down). The novelty of the monochromator also arises from a combination of distinct technical features. All motions are driven from outside the vacuum system ensuring perfect UHV compatability. Large external rotation-, tilt- and translation-stages ensure excellent positioning. The design is simple and low levels of maintenance are required due to the strict use of commercial motion devices.

The multicrystal monochromator for the TROIKA I branch (ID10A) is designed to support three X-ray-transparent crystals in Laue geometry: a (100)-oriented diamond allowing reflection from (220) in symmetric Laue geometry, a (100)-oriented diamond allowing reflection from (111) in asymmetric Laue geometry and a beryllium crystal allowing reflection from (200) in symmetric Laue geometry. There is also an Si(111) crystal in symmetric Bragg geometry. Fig. 1 shows the energy range covered by the monochromator crystals. The intrinsic energy resolution dE/E given in the insert is calculated for the symmetric Bragg case and linear σ-polarization. The TROIKA II branch (ID10B) is also equipped with a multicrystal monochromator. The beam from this monochromator impinges on a second crystal offset horizontally by 850 mm from the first monochromator crystal to produce a monochromatic beam travelling parallel to the white-beam path. This double-crystal configuration operates with two C(111) crystals in symmetric Bragg geometry, or with two C(100) crystals allowing reflection from (111) lattice planes in asymmetric Laue geometry, or with two Be(002) mosaic crystals in symmetric Laue geometry (Grübel *et al.*, 1996). Energy tuning involves a translation of the second crystal parallel to the white-beam axis and the stroke of the translation allows X-ray energies of 8–13 keV for the diamond double-crystal configuration.

2. Multicrystal holder

The multicrystal holder is a key element of the monochromator and consists of a specially shaped monolithic Cu block, schematically shown in Fig. 2(*a*), and its connecting parts to the monochromator assembly (not shown). The Cu body allows the vertical stacking of up to four monochromator crystals in different scattering geometries (*e.g.* symmetric Bragg geometry, symmetric and asymmetric Laue geometry). The holder is designed such that (*a*) the scattering vectors $q(hkl)$ for the different crystals are parallel, so that a single tilt motion about a common tilt-axis bends the beam out of the horizontal plane, (*b*) the transmitted beam can exit the holder, (*c*) common cooling is provided for all crystals and (*d*) it can be translated vertically in order to elevate the different crystals into the white-beam axis.

Fig. 2(*b*) shows top views of three cuts through the holder as indicated in Fig. 2(*a*). The top cut refers to the symmetric Bragg geometry at a 35° Bragg angle. The crystal [*e.g.* Si(111) or C(111)] is not directly attached to the Cu body of the holder but is held in an insert, which is custom-designed for every individual crystal. Fig. 2(*c*) shows a side view (cut *DD*) of such an insert. The crystal is supported by a lip on the bottom of the insert and is secured with two horizontal strips at the bottom and the top of the insert. The Cu inserts are nickel-coated and permit the use of a thin layer of indium–gallium eutectic to ensure good thermal contact

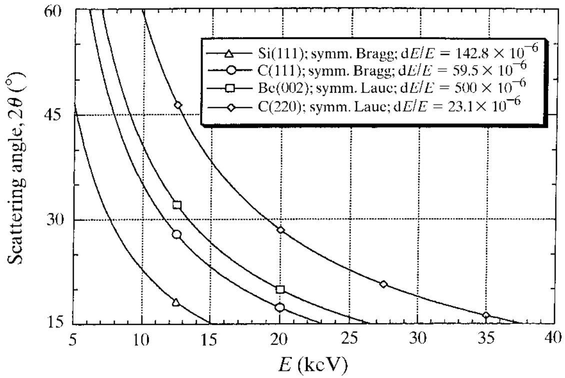

Figure 1
Energy range covered by the multicrystal monochromator. The intrinsic energy resolution dE/E is calculated for the symmetrical Bragg case and linear σ-polarization. The values for Be(002) refer to a 200 µrad mosaic crystal. The intrinsic energy resolution for (111) reflection from a (100)-oriented diamond in asymmetric Laue geometry is dE/E = 46 × 10^{-6} at 9 keV. For incident π-polarization the polarization factor $\cos(2\theta)$ has to be taken into account.

between the crystal and the insert. Similar custom inserts have also been designed for the other scattering geometries. The multicrystal holder is water-cooled, which has been shown to be sufficient for transparent crystals (Als-Nielsen, Freund, Wulff *et al.*, 1994); the position of the cooling channels is also indicated in Figs. 2(*a*) and 2(*b*). Silicon crystals can be used in a very fine collimated white beam. The holder is compatible with optional cryogenic cooling that would allow the use of silicon under full thermal load. The middle and bottom cuts in Fig. 2(*b*) show arrangements for the symmetric Laue geometry, *e.g.* (220) reflection from a diamond with (100)-oriented surface, and for an asymmetric Laue geometry, *e.g.* (111) reflection from a similar (100)-oriented diamond, respectively. The multicrystal holder has provision for two thermocouples. The holder (10 in Fig. 3) is connected *via* a stainless-steel rod to a vacuum flange on top of the monochromator assembly (see Fig. 3). A 35 mm UHV flange on top of the main flange accommodates thermocouple feedthroughs and cooling feedthroughs (1 in Fig. 3). The alignment of the (vertical) multicrystal-holder axis is achieved with the help of a special alignment tool (not described in this paper). Reproducible positioning of the holder in the monochromator assembly is afterwards ensured by three (ceramic) kinematic mounts (Slocum, 1992) on top of the assembly.

3. Monochromator assembly

The monochromator assembly provides high-precision motion under UHV conditions according to the technical specifications given in Table 1. Fig. 3 shows a schematic assembly drawing of the monochromator and Fig. 5 shows a three-dimensional view of the device. The main components of the assembly are the vacuum system, a differentially pumped rotary seal and a rotation and tilt stage combined with separate vertical and horizontal translations. These elements are described in the following paragraphs.

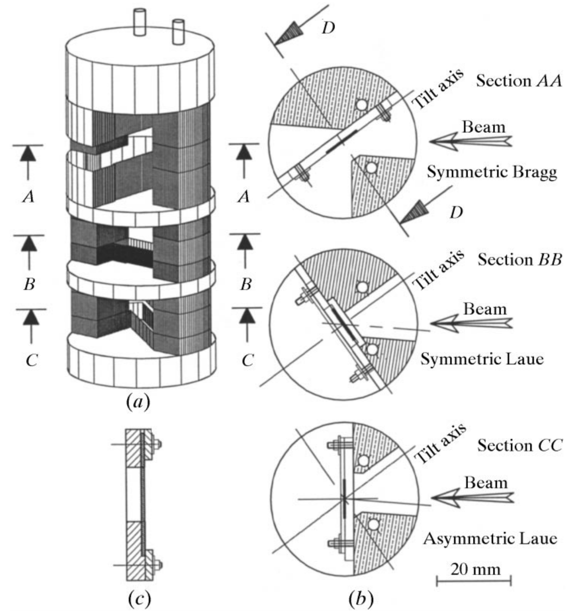

Figure 2
(*a*) Schematic view of the multicrystal holder. (*b*) Top views of three horizontal cuts (levels *AA*, *BB* and *CC*) through the holder. The three cuts refer to a symmetric Bragg geometry (top) at 35° scattering angle, a symmetric Laue (middle) and an asymmetric Laue geometry (bottom). (*c*) Side view of the crystal-mount insert (cut *DD*).

Table 1
Technical specifications of monochromator motions.

	Stroke	Resolution	Reference in Fig. 3
Rotation	0 to 45°	1×10^{-4} °	7
Tilt	−10 to +5°	1×10^{-3} °	6
z-motion	50 mm	5 µm	5
xy-adjustment	±2.5 mm	1 µm	2

The monochromator vessel (12 in Figs. 3 and 5) is a 304 l stainless-steel chamber (4 mm wall-thickness) mounted on a support structure (not shown). Two 35 mm UHV flanges (white-beam entrance and exit) connect the vessel to the beamline vacuum system. The monochromator vacuum system, including the main vessel, the vacuum housing (13 in Fig. 3) and the multicrystal holder, typically operates at 1×10^{-8} mbar when pumped with a 230 l s^{-1} ion pump located underneath the vacuum vessel. The monochromatic beam exits the monochromator *via* a rectangular Be window (11 in Figs. 3 and 5) sealed with a thin gold or lead wire. The Be window (500 µm thickness) allows horizontal opening angles from 15° to 80° relative to the forward direction and vertical opening angles from +5° (upwards) to −15° (downwards).

A double-stage differentially pumped rotary seal (9 in Fig. 3) is mounted on top of the vessel. The rotatable part (sketched schematically in Fig. 3) is connected to the bottom of the vacuum housing (13 in Fig. 3) and to a rotatable platform that supports all the monochromator mechanics, including the goniometer tilt stages (6 in Fig. 3), the *z*-motion (5 in Fig. 3), the mounting and alignment support for the multicrystal holder and the upper section of the vacuum housing. The rotatable platform is attached to a turntable (7 in Fig. 3), providing adjustment of the scattering angle by rotating the complete monochromator assembly (shaded components in Fig. 3) on top of the rotary table including the multicrystal holder. The turntable has a concentricity ≤7 µm and a wobble ≤50 µrad and is equipped with a 1:100 reducing gear.

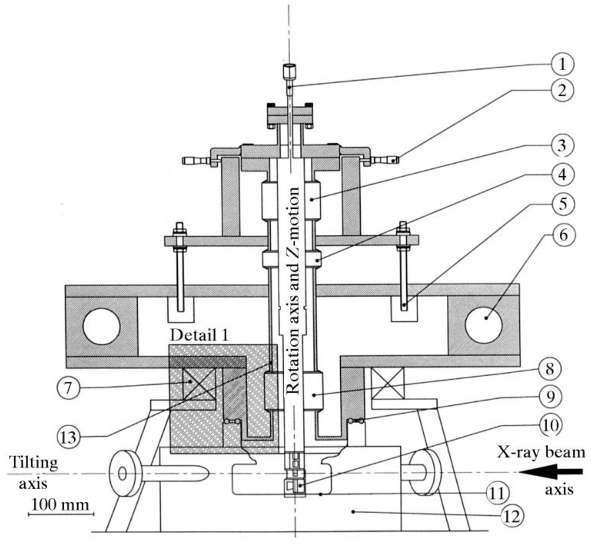

Figure 3
Schematic assembly drawing of the multicrystal monochromator. The rotary-seal section (detail 1) is detailed in Fig. 4. (1) Water cooling; (2) *xy*-adjustment; (3) *xy*-bellows; (4) *z*-motion bellows; (5) *z*-motion; (6) goniometer tilt stages; (7) rotation; (8) tilt-motion bellows; (9) pumped rotary seals; (10) multicrystal holder; (11) Be window; (12) UHV vessel; (13) vacuum housing.

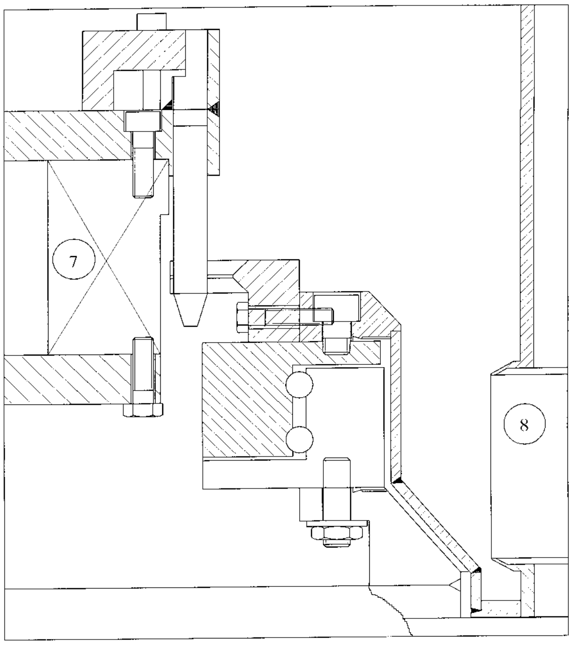

Figure 4
Detail of the pumped rotary-seal section (detail 1 in Fig. 3). Shaded parts are rotatable.

An incremental encoder, attached just above the turntable, ensures precise positioning of the scattering angle. The turntable is attached to its own support structure (see Figs. 3 and 5) and levelled such that the rotation axis of the turntable is vertical.

The tilt motion of the monochromator is achieved with two goniometers (6 in Figs. 3 and 5) mounted on top of the rotatable platform. A common horizontal tilt axis for the goniometers intercepting the (vertical) rotation axis is defined during the alignment of the assembly. The two tilt motors are microstepper driven and are controlled *via* a single driver card to avoid synchronization errors. A custom-made bellows (8 in Fig. 3) is directly connected to the vacuum housing and to the rotating part of the differentially pumped rotary seal and allows the tilt motion of the crystal holder under vacuum. A detail of the rotary-seal/rotatable-platform section is shown in Fig. 4. It shows in particular the location of a connecting pin between the rotatable platform and the rotary seal, preventing an eventual torsion of the the tilt bellows (8 in Fig. 3) upon rotation.

A vertical translation stage allows the positioning of the four crystals in the white-beam axis. The synchronization of the two elevator elements (5 in Fig. 3) arranged symmetrically around the vertical axis is ensured by a tooth-belt and gear system driven by a single stepping motor (see Fig. 5). The linearity of the z-displacement is guaranteed by two linear ball guides. The co-linearity between the z-motion and the vertical rotation axis is adjusted during the assembly and alignment of the monochromator. The z-motion bellows (4 in Fig. 3), connected to the vacuum housing, enables a stroke of 50 mm. An accurate home position switch provides an external reference for the vertical positioning of the multicrystal holder.

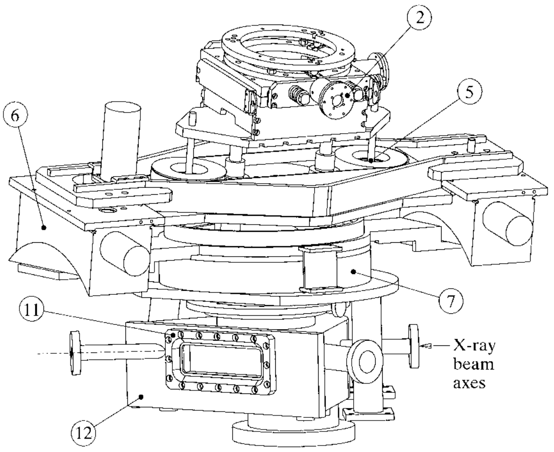

Figure 5
Three-dimensional view of monochromator assembly. (See Fig. 3 for numbering.)

In order to compensate for alignment errors during the mounting of the individual crystals, an xy-stage (2 in Figs. 3 and 5) is stacked on top of the z-motion. A separate bellows (3 in Fig. 3) enables an xy-displacement of the multicrystal holder under UHV conditions. The xyz coordinates for each individual crystal are determined in the assembly phase and afterwards optimized with the X-ray beam. Once optimized and stored in the computer database this information allows one to switch between the crystals without further alignment procedures.

The final characterization in the laboratory uses a sphere alignment support mounted in place of the multicrystal holder. An auto-collimated laser beam follows the displacement of the sphere while the whole range of motions is covered. The resulting sphere of confusion of the monochromator is typically 50 µm.

4. Summary

A total of four multicrystal monochromators have been assembled. All technical specifications have been reached. Three devices are presently under commissioning at ESRF beamlines (ID10A, ID10B, ID14).

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