Laue –Laue monochromator for ID11 beamline at ESRF(†)

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Abstract

Laue-Laue crystal monochromator design issues and performances will be reported. A horizontally scattering fixed exit Si (111) monochromator operating under high heat loads has been installed on the ID11 beamline at ESRF. The energy is tuneable in the range 22.7 to 141.7 keV (~5.0° to 0.8°). The main construction issues are: 1) the very compact configuration. Crystals can be driven along the beam path very close to each other; 2) The axes of the 3 rotations converge in the middle of both crystals to minimize parasitic displacements during adjustment; 3) Crystal benders have been designed to accept different crystal shapes. Both crystals can translate out of the beam in the transverse direction since the white beam has to be used for experiments with different devices. Piezoelectric actuators have been mounted on both crystals to enable energy scans and active feedback. Both crystals are water cooled and are in contact with an InGa bath in a vacuum chamber. Between the two stages there is a protective tungsten beam mask to stop the straight pink beam. Two additional linear stages are provided for filter selection and diode insertion or removal.

1. Introduction

ID11 is a multipurpose beamline dedicated to diffraction experiments in the field of materials science. The beamline has two experimental hutches and an optics hutch, which are normally served by a pair of in-vacuum undulators, giving excellent flux at high x-ray energies. The optics hutch is installed directly after the front end, with a Si (111) Bragg-Bragg monochromator providing monochromatic beam to both experimental hutches with a band pass of $dE/E \sim 10^{-4}$. The experimental hutches are located at distances of 40 and 96 meters from the x-ray source. A longer distance to the source gives an improved demagnification of the focal spot size for producing micro- and nano- focussed x-ray beams.

The limitations of Bragg type monochromator constructions become evident at energies above 50 keV. At higher x-ray energies the divergence of the ESRF x-ray source is greater than the angular acceptance of a perfect Si (111) crystal. This mismatch can be overcome using cylindrically bent perfect Si crystals in Laue geometry [1] [2]. Versatility and efficiency are the advantages of bent crystals as monochromators: the optical performance can be adapted to the specific experimental needs.

The design of the Laue-Laue monochromator had to meet specific operation conditions on the ID11 beamline: a) a small ’fixed exit’ offset of 10 – 15 mm; b) provide low energies (about 23 keV) where the crystals are very close to each other (58 mm); c) the mechanical bender should accept rectangular and triangular crystals. Such requirements made the design quite challenging and led to a very compact system where the crystal rotation and tilts are realized by flexure mechanics. Also the rotation can be offset from 0° to 15° to accommodate crystals with different asymmetric cuts. A photodiode and absorption foils inside the monochromator chamber allow the easy alignment and calibration of the instrument in the x-ray beam, particularly the bending of the first crystal. A horizontal scattering geometry was chosen to preserve the quality of the source in the vertical plane. Similar horizontal monochromators exist at ESRF beamline ID15 [1] [3], whereas a vertical one with cryogenic cooling is installed at APS beamline SRI-CAT [2]. A horizontal geometry was chosen to allow simple and efficient cooling and minimize the effect on the vertical source size to allow subsequent focussing with another element.

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2. Laue-Laue Physics in Details

The concept of bent Laue type monochromators is very attractive since the band pass can be matched the specific needs of an experiment. In addition, compared to flat crystals, asymmetrically cut bent crystals can deliver up to 10 times higher photon flux particularly at higher energies. If the crystal is bent to match the Rowland circle geometry all rays of a divergent white beam incident on different parts of the crystal are reflected with the same angle.

The band pass of the monochromator crystal is then defined by the crystal thickness, the asymmetric cut χ, and the bending radius. In order to optimize the flux of the monochromator a Si(111) crystal has been chosen. The crystal thickness (2.5 mm) and asymmetric cut (χ= 12.5°) were defined by the desired energy resolution of $dE/E \sim 10^{-3}$, which is suitable for many diffraction experiments. The optimal combination of crystal parameters was calculated using a computer program supplied by Veijo Honkimäki [4]. The mechanical support has been designed to accept crystals with thicknesses up to 5mm and asymmetric cuts up to $\chi = 15°$. The asymmetric cut requires a fixed offset rotation of the crystal by the same amount, due to the limited range of the main axis. In order to compensate any offsets in the angle scale introduced by the crystal mounting and then bending, the asymmetric cut was chosen to be smaller than the limiting value of $\chi = 15°$. Initial commissioning of the instrument with the 2.5 mm crystal indicates this was a good compromise for the large working energy range. Clearly, a thinner crystal would be preferred for lower energies, and a thicker crystal for higher energies.

3. Design Issues and Criteria

The monochromator (*Figure 1a*) consists of 14 motorized axes all equipped with limit switches. Among them, 7 are encoded axes. The main rotation (Bragg angle selection) axes are equipped with a piezo actuator for fine movements. The encoder detects the summed angular displacement of the stepper motor and piezo actuator. The main constraint of the design is the need of an extremely compact configuration because both crystals have to be positioned very close one to each other (*Figure 2*) in order to work at low energies. A long encoded linear stage is placed on the main table; the stack of axes of the first crystal can be moved along the beam. The rotating part is completed by a complex flexure that allows the tip-tilt adjustment of the crystal by means of two motorized actuators. The axes of the 3 rotations converge in the middle of the two crystals to minimize the parasitic displacement during adjustment. Between the two stages there is a protective water cooled tungsten beam mask to stop the white beam. Two additional linear stages allow filter selection and diode insertion or removal. Two benders have been foreseen, one for each crystal, and are configurable for different crystal shapes and thicknesses.

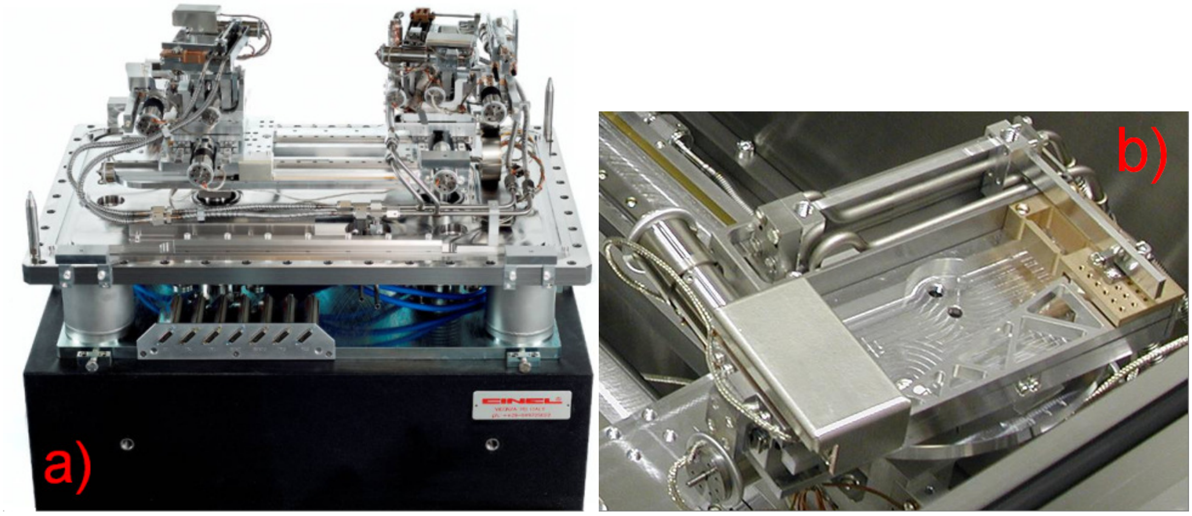

Figure 1: a) Laue-Laue monochromator (860 mm long, 590 wide); b) bender for rectangular crystals

A granite block acts as an interface between the vertical adjustment system and the main plate supporting both chamber and internal mechanisms. The main plate is fixed to the granite by means of screws in order to allow the alignment of the overall system. The chamber and the mechanisms inside have a fixed relative positioning hence the pre-alignment could be done with both systems together. The internal mechanisms are installed over a common table suspended over three columns separated from the chamber by means of bellows that make the system insensitive to the vacuum loads occurring during the pump down phase.

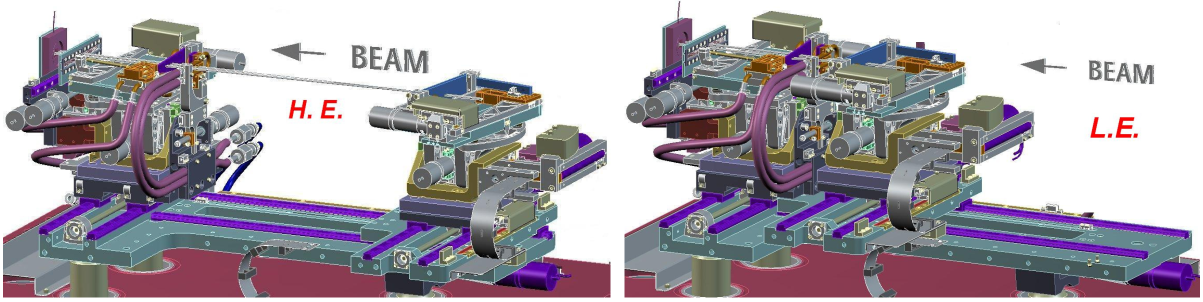

Figure 2: High Energy and Low Energy Configuration

4. Beam Tests

The bending radius of the monochromator crystal was adjusted to match the fan of the radiation from the synchrotron light source. All rays across the fan should be incident onto the internal crystal planes at the same angle. The bending radius can be calibrated by measuring the apparent shift of an x-ray absorption edge at different positions on the crystal.

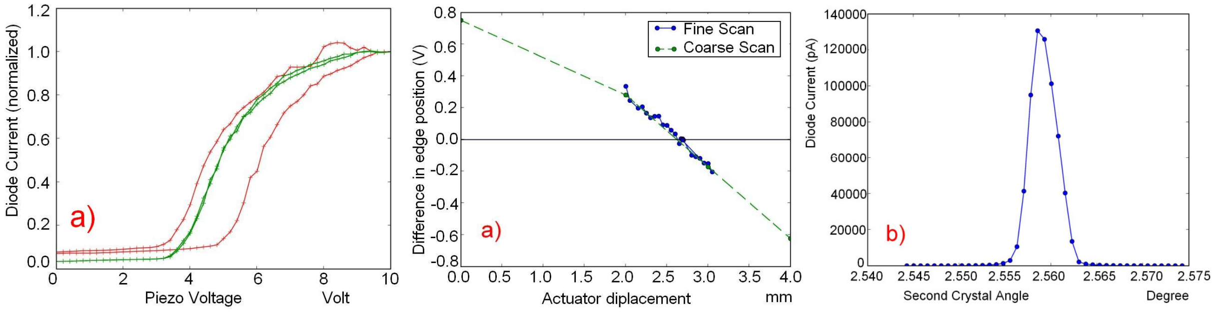

Figure 3: a) Measurements of the Tin absorption edge using the foils and diode mounted inside the monochromator vacuum chamber. The red traces are related to measurements taken at different positions on a flat crystal while the green traces are the same scans after optimisation of the bending.; b) Optimization of the first crystal bending at Tin edge; difference in edge position as a function of first crystal bending actuator; c) Rocking curve measured at 44.3 keV

Figure 3a shows the absorption edge profiles measured by scanning the first crystal angle via the piezoelectric pusher. The red traces have been measured with an incident beam taken from 1 mm and -1 mm away from the centre of the radiation fan. While increasing the bending radius the scans were repeated and the difference in edge position was measured as a function of the bending. Green traces are the evidence of the good system performance after optimisation of the bending of the first crystal.

The bending radius of the second crystal was then adjusted to match the first by inspection of the rocking curve. *Figure 3b* shows the offset of the edge positions as the bending actuator displacement was adjusted, whereas the rocking curve after optimization is shown in *Figure 3c*.

1.1.References

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