Test of a sagittal bent high-energy monochromator

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The utilization of sagittal bent symmetric Laue crystals for a broad band and source size conserving monochromator for high-energy undulator beams is investigated. Existing high-energy beamlines at third generation synchrotron sources mostly employ asymmetric meridionally bent Laue monochromators crystals. The proposed scheme provides a significantly larger strain gradient and therefore ratio of the bandwidth to the beam path length in the crystal. This is particularly advantageous for large source-to-monochromator distances (e.g. 100 m at the P21 beamline) where meridional Rowland bending requires rather thick crystals for significant band width broadening, and at the very attractive lower end of the high-energy spectrum (30-40 keV) where attenuation becomes limiting. Furthermore, the symmetric diffraction geometry results in several practical advantages, most notably temperature gradients from external cooling and the primary bending axis are perpendicular to the diffraction plane. The band width broadening in symmetric Laue geometry is due to the anisotropic elasticity of silicon and has been predicted but not yet experimentally quantified [1].

The geometry of the bent crystal is sketched in Figure 1a. Sagittal bending moments are applied as indicated resulting in an anticlastic bending in the meridional plane (while the sagittal bending is invisible in the diffraction plane). The ratio of the sagittal to anticlastic bending depends on the (anisotropic) Poisson ratio and on the crystal dimensions and boundary constraints by the bender (clamping). The crystal dimensions were chosen by FEM simulations such that an anticlastic bending radius of 100 m should coincide with a rocking curve width of 50 µrad (energy bandwidths of 0.1% and 0.25% at 40 keV and 100 keV, respectively). The crystal orientation is crucial since it results in a large anisotropy of the Poisson ratio in the diffraction plane, and therefore curvature of the (111) lattice planes, while a twist of the crystal is prevented by the (110) mirror plane.

A prototype bender was characterized in the EH2 physics hutch of the P07 beamline at an energy of 78.9 keV. A narrow bandwidth beam was provided by a vertically diffracting (220) channel cut Si crystal downstream of the bent Laue-Laue primary monochromator. The beamsize was 0.1×0.1 mm². The curvatures were measured by translating the crystal through the beam and evaluating the peak shift of rocking curves. Wobble of the translation stages and other drifts were monitored by diffraction from a flat reference crystal mounted right in front of the bent crystal (Figure 1b).

Figure 1: (a) Bending geometry and crystal orientation. The thickness of the crystal was 1.5 mm. (b) Principle of curvature measurement by crystal translation and a flat reference crystal. The detector was either placed in the incident beam or was intersecting both diffracted beams.
The crystal was bent to a nominal sagittal radius of 9.3 m. The peak shift due to meridional bending was measured along seven horizontal traces spaced vertically by 1 mm steps (Figure 2a). The local bending radius was evaluated by differentiation and is shown in Figure 2b. The meridional bending radius at the crystal center was 137 m. The (meridional) (111) rocking curves of the bent and reference crystals are shown in Figure 2c (‘Mono’ and ‘Ref’, respectively). The rocking curve of the bent crystal had a FWHM of 44 µrad and reflectivity of 94%.

![Peak shift](image1)
![Bending radius vs. crystal position](image2)
![(111) rocking curves](image3)

Figure 2: (a) Peak shifts due to anticlastic bending. ‘x,’ denotes the horizontal x-coordinate along the crystal (cf. Figure 1b). The vertical z-position is indicated in the legend [mm]. (b) Bending radius vs. crystal position. The center of the crystal is at zero. (c) (111) rocking curves of the bent crystal (Mono) and the reference crystal (Ref).

The peak shifts as function of the horizontal beam position were fitted by 5th order polynomials. The residuals were below 0.5 µrad demonstrating the precision of the measurement. The observation that the crystal curves more at the edges than in the center is predicted by FEM simulations and caused by the plate like crystal shape and boundary conditions. Still, at the center of the crystal and over the central cone of an undulator peak the incident angles in Rowland geometry would change by less than 0.5 µrad which is acceptable. The absolute meridional bending radius of 137 m is significantly larger than the 100 m predicted by FEM simulations. This is partially explained by a reduced sagittal bending (which was also measured to be a radius of 9.6 m) and rounded edges of the actual crystal which were not considered in the FEM simulation. The rocking curve width is then in fair agreement with the FEM simulation. The peak reflectivity of 94% is in excellent agreement with calculations of the critical strain gradient [2]. The absorption is only 7.5% due to the minimized path length in the crystal. Thus, the experimental data are very promising for the use of symmetric (111) sagittal bent crystals as Laue-Laue monochromators.

In Figure 2a a systematical vertical shift of the peak shift traces is discernable as function of the vertical beam position on the crystal. This shift is due to a twist of the crystal imposed by the bending device. The twist can be compensated but online correction was not possible during the beam time.

References