Harmonic selection by a bent Laue crystal

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Introduction

The harmonics from an undulator/double-crystal monochromator combination can be used effectively for experiments at higher energies [for example, extended x-ray absorption fine structure (EXAFS) of high-Z materials]. The selection of the desired harmonic without contamination by the fundamental or other harmonics presents a challenge that is generally met by beam filtration and harmonic-rejection mirrors. As the energy of the desired harmonic rises, however, the use of a mirror becomes increasingly difficult.

While diffraction from a post monochromator can be used to select the desired harmonic energy, perfect crystals have very narrow reflectivity widths and are difficult to keep in tune as energy is swept during an EXAFS scan, for example. The use of a bent crystal in the Laue geometry solves this problem by providing an easily aligned optic with a broad reflectivity width [1].

A Si(111) from a beamline monochromator and to use a post-monochromator that also uses the Si(111), but diffracting a harmonic (Nx the fundamental energy). The beamline monochromator will prepare a beam at the fundamental energy setting, E, and with lesser intensity energies at 3E, 4E, 5E, 7E, 8E, 9E, 10E, etc. The missing energies at 2E and 6E correspond to forbidden (nearly) reflections from the Si(111) monochromator. If the second harmonic is to be selected (3x the fundamental energy, 3E) then the Si(111) post monochromator is set to diffract this energy. This combination will eliminate the fundamental energy, E, pass the second harmonic, 3E; and eliminate the 4E, 5E, 7E, and 8E energies. The eighth harmonic (9E) is the next energy passed by the mechanism, most likely having a very low flux.

Methods and Materials

The experiments were performed at the MR-CAT (sector 10) and Bio-CAT (sector 18) beamlines at the Advanced Photon Source (APS). Each of the beamlines the beamline monochromator was a Si(111) double-crystal mechanism with no mirror or post-monochromator optical elements in place. Experiments were performed at fundamental energies of 7 and 10 keV for both the undulator and the monochromator. In this configuration, the undulator produces significant flux at the desired harmonics.
A crystal plate with a [100] surface normal was able to achieve an optimal crystal geometry. The reflection chosen was (111) which is asymmetric with the crystal surface (χ = 35.3 degrees). In order to achieve a cylindrical bend, the crystal plate was cut to a triangular shape (0.2 mm thickness, 25 mm base and 70 mm height), held at the base and deflected at the apex by a ball bearing and spring assembly to achieve a variable bending radius. The optimized bending radius for the 20 keV energy range using the Si(111) reflection was approximately 1.7 m. This radius was set using an optical light source.

The bending mechanism and crystal assembly were mounted on an IUCr (or ACA) mount for placement on a diffractometer. The crystal was rotated so that the beam was parallel to the Si(111) lattice planes and was subsequently rotated by $\pm\theta_B$ to diffract the harmonic from the beam. The incident, transmitted, and diffracted beams were detected by an ionization chamber. For spectral measurements, a solid state detector (intrinsic Ge) and an Al foil scatterer were placed in a vertical. Compton scattering was chosen to measure the spectrum since the intensity of scatter could be controlled by varying the thickness of the Al foil, varying the distance from the scatterer to the detector, and by limiting the acceptance of the detector. This spectral measurement technique also eliminated pileup that can mask and distort the Compton spectrum. For these measurements, a scattering angle of 90 degrees was used.

Results

Measurements were made primarily at two energies (7 and 10 keV fundamental energies). Rocking curves of the diffracted beam and the transmitted beam were measured using ionization chambers whose response function varies with beam energy. Thus, as the incident and transmitted beams contain both fundamental and harmonic energies, the extinction of the transmitted beam will not equal the intensity observed in the diffracted beam.

At these fundamental energies, the cleaner was set to diffract the second (3x the fundamental) harmonic. The spectra from the solid state detector were used to confirm the spectral (harmonic) content of both the incident and the ‘cleaned’ (diffracted) beam. A representative spectrum obtained for the 3 x 10 keV (30 keV) case is shown in Figure 1. The spectrum measured shows the effect of the cleaner on the diffracted beam compared to the incident beam. These spectra were used to estimate the 30 keV reflectivity of 70% by the cleaner.

Discussion

Over the past several years, bent Laue crystals have been used for a number of applications [2–4]. A surprising aspect of diffraction from an optimized Laue geometry is the efficiency that such a bent Laue crystal may have [1, 2, and 5]. A major advantage of a bent crystal geometry is the enhanced reflectivity width due to the bending of the lattice planes in the transmission geometry. For most purposes, a kinematic approximation can be made for the diffracted intensity if the crystal is bent sufficiently for the crystal to behave as a fully mosaic crystal. In this case, the integrated intensity is that given by the kinematic theory and is assumed to be uniform in intensity over the reflectivity width. The results show that the harmonics from a double-crystal monochromator can be efficiently diffracted by the bent crystal 'cleaner.' A maximum reflectivity for a single cleaner is in excess of 70%. For most measurements, a single-crystal device is not optimal because the diffracted beam is deflected from the line of sight. A double-crystal device is being designed that will re-establish the direct beam direction for the 'cleaned' beam.

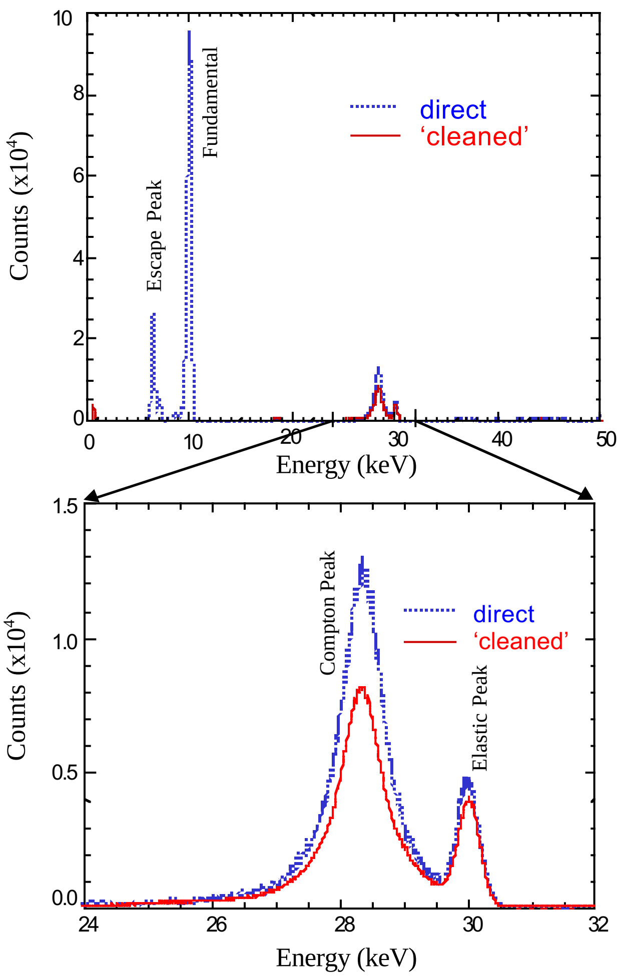

Figure 1: Measured spectra of the direct and diffracted beams from the bent Laue crystal 30 keV. The top part shows the complete spectrum, the bottom shows the region about 30 keV.

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