Commissioning of a Diamond Phase Retarder at 9-ID-B for the Production of Circular Polarized X-rays

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Introduction

Use of phase retarders in the production of circular polarized x-rays has become a well-established method at synchrotron sources.[1] They are convenient to set up, produce a high degree of circular polarization, and can provide rapid helicity-switching. Due to the high flux of third-generation synchrotron sources, it has now become feasible to do resonance x-ray magnetic scattering measurements at the K edges of transition elements. To access this energy range, we set up a 500 micron (001) diamond wafer diffracting in the asymmetric Laue geometry. Phase retarders operate on the principal that, according to the dynamical theory of diffraction, wave fields with different linear polarizations propagate with different phase velocities inside the crystal. The induced phase difference is a function of the deviation from the exact Bragg condition; thereby, by selecting an appropriate offset angle, the crystal can be made to perform as a quarter- or half-wave plate. For the purpose of this characterization, the (111) Laue reflection was used and the transmitted beam was analyzed for circular polarization content.

Methods

The 9-ID beamline at CMC-CAT has an undulator A insertion device, a cryogenically cooled Si (111) monochromator, and, currently, a vertical focusing mirror (VFM) that focuses the beam to a vertical size of 90 microns. The experimental hutches are at a distance of 60 to 80 m from the source, hence beam divergence effects can be significantly large. The reflected, focused beam from the VFM was incident on the diamond placed about 60 m from the source. The diamond was aligned so that its (111) diffraction plane was at 45 degrees to the vertical plane. The undiffracted, transmitted beam was then incident on a harmonic rejection mirror. To determine the degree of circular polarization as a function of the offset angle, the magnetic circular dichroism signal was measured from a 75-micron-thick ion foil held between the poles of an electromagnet. The energy was tuned to the Fe K edge of 7.112 keV. For each angular offset position, the asymmetry ratio was measured by flipping the polarity of the magnet. Ion chambers before and after the Fe foil were used to monitor the signal.

Results

The asymmetry ratio, which is the difference signal measured by flipping the polarity of the magnet, normalized by the total summed signal, is directly related to the degree of circular polarization in the beam. This degree of circular polarization is given by the Stokes-Poincaré polarization parameter, P_3, which when equal to ±1, represents complete left- or right-handed circular polarization. In order to extract P_3 from the asymmetry ratio, R, we compared the data to theoretical simulations made using dynamical diffraction calculations made with an 8x8 matrix formulation.[2] The 8x8 formulation calculates the real and imaginary components of the electromagnetic fields needed to calculate the amplitude and phase of reflectivity and transmission coefficients. It was applied to the case at hand, that is an asymmetric Laue case. The Laue-diffracted beams, as well as the transmitted beams were computed, and P_3 was obtained for the transmitted beam after making a rotation of the 8-element eigenvectors that contain s-polarization and p-polarization field-components. We note that an asymmetric Laue-case phase plate for the production of circularly polarized x-rays has not yet been explored, so far as we know. One possible utility of this case arises from the ability to construct a beamline with side-station reflections and an in-line circularly polarized beam. Furthermore, by using an asymmetric reflection, beamline optics designers have a means to manipulate the beam size and divergence. For example, the angular range over which P_3 is large in the data shown in Fig. 1 is affected by the dynamical b-factor for asymmetric reflections.[3]

Figure 1 plots the experimental data and theoretical simulation as a function of the diamond offset angle. It is seen that when operating as a quarter-wave plate, the phase retarder can produce a P_3 of 0.8. The flux measured at the sample, after transmission through the diamond and harmonic rejection was 5×10^{12} photons/s.

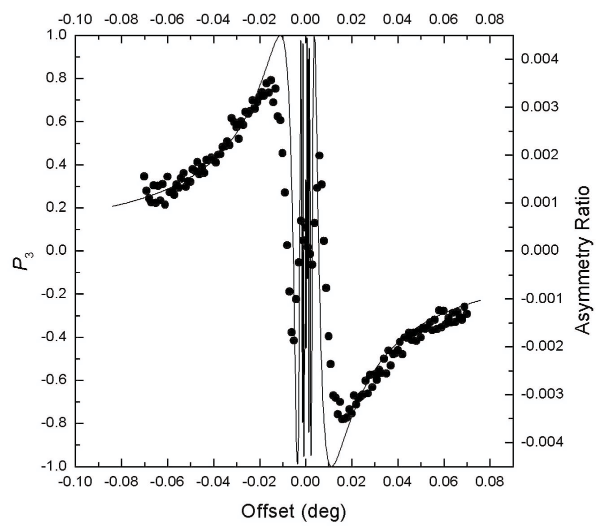

FIG. 1. Performance of the diamond phase retarder in terms of the Stokes-Poincaré parameter, P_3 (dots). On the right side, the measured asymmetry ratio, R, is given. The solid line is the theoretical calculation of the same parameter.

Discussion

Improvement in the phase retarder performance, in terms of P_3 and flux, is expected once the horizontal focusing mirror (HFM) is in operation (May 2001). The VFM+HFM combination will form a Kirkpatrick-Baez configuration allowing a 1:1 image of the souce at the sample. Furthermore, it will be possible to collimate the beam, thus eliminating completely the degrading effects of angular divergence.

Magnetic reflectivity measurements of a Fe/Cr double superlattice multilayer at the Fe K edge were performed using this phase retarder at CMC. The data are presented in a separate highlight in this volume and demonstrate that the phase retarder performed sufficiently well to allow these first detailed measurements to be made.

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References

[1] J.C. Lang and G. Srajer, Rev. Sci. Instrum. **66**, 1540 (1995)

[2] D.W. Berreman and A.T. Macrander, Phys. Rev. B **37**, 6030 (1988).

[3] W.H. Zachariasen, *Theory of X-ray Diffraction in Crystals* (Dover, NY, 1945).