Circularly Polarized X-rays in Nuclear Resonant Scattering

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Introduction

Synchrotron radiation is usually linearly polarized in the orbital plane. One way to create circularly polarized x-rays with synchrotron radiation sources [1] is by using a perfect-crystal Bragg transmission phase retarder [2]. It consists of a thin single crystal that is operated near one of the crystal reflections. It transforms linear polarization to circular polarization by inducing a phase retardation between the σ and π components of the incoming radiation. The degree of circular polarization after the phase retarder can be determined via multibeam diffraction [3] or by means of a perfect-crystal polarization analyzer [4]. Here we introduce an alternative method that uses nuclear resonant forward scattering [5].

Methods and Materials

The nuclear resonant scattered wave field will depend on the nuclear and material properties of the scatterer and on the polarization properties of the incident radiation wave field. If one chooses a sample for which the nuclear response is known (e.g., the hyperfine fields acting on the nucleus are known), one can use it as an "analyzer" to determine the degree of circular polarization. The polarization state of the incident radiation can be characterized by means of the three parameters P, θ_M, and θ_C, where P = the degree of polarization, θ_M = the mixing angle that allows one to change the polarization state from linear (θ_M = 0°) to left circular (θ_M = +90°) or right circular (θ_M = -90°) and elliptical (intermediate angles), and θ_C = the canting angle that allows one to rotate the polarization basis.

If one knows the nuclear response of the sample and the polarization sensitivity of the detector, one can fit the experimental nuclear resonant scattering intensity spectra for P, θ_M, and θ_C. Once these parameters have been obtained, one can calculate to what degree the radiation was circularly polarized by means of the following formula:

$$P = P_C \sin \theta_M \quad (1)$$

Note that the above expression is independent of the canting angle θ_C. As a result, once the parameters P and θ_M have been obtained from fitting the experimental data, one can immediately calculate the degree of circular polarization P_C of the radiation wave field incident on the sample (i.e., the radiation wave field directly after the phase retarder).

Results

Figure 1 shows the experimental setup used to generate and characterize circularly polarized radiation. The phase retarder is a diamond (1 1 1) crystal. The Bragg angle is determined by rocking the diamond crystal while monitoring the reflected intensity with a PIN diode (see Fig. 1). Subsequently, the phase retarder is detuned from exact Bragg condition by slightly offsetting the incidence angle. In this way, the transmitted beam will become circularly polarized. The degree of circular polarization as a function of the offset angle Δθ is measured via nuclear resonant forward scattering on a 1.0-μm-thick Fe foil (95% enriched in iron-57) magnetized perpendicular to the synchrotron plane, the local magnetic field at the nucleus being -32.7 T. The incident radiation was monochromatized to 2 meV around the 14.413-keV nuclear resonance of iron-57. The resonant forward scattered intensity was recorded as a function of time after the arrival of the synchrotron pulse by means of an avalanche photodiode detector (APD).

Fig. 2 shows three time spectra taken at different offset angles. The spectra were fit with only θ_M as the free parameter. P was found to be 100%, and θ_C was found to be 0°. One can see how the mixing angle decreases as the offset Δθ from the exact Bragg angle increases. By using Eq. 1, one can calculate the degree of circular polarization P_C. For the three spectra shown in Fig. 2, P_C is 99.9%, 93.4%, and 68.8%, respectively.

Discussion

In conclusion, we have successfully converted linearly polarized synchrotron radiation to circularly polarized radiation at 14.413 keV by using an x-ray phase retarder. The degree of circular polarization was determined by

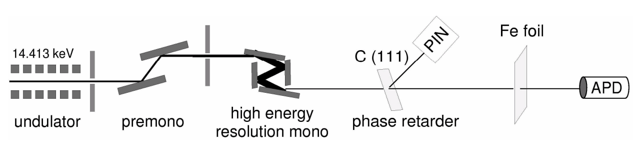

FIG. 1. Experimental setup for generating and characterizing circularly polarized radiation.

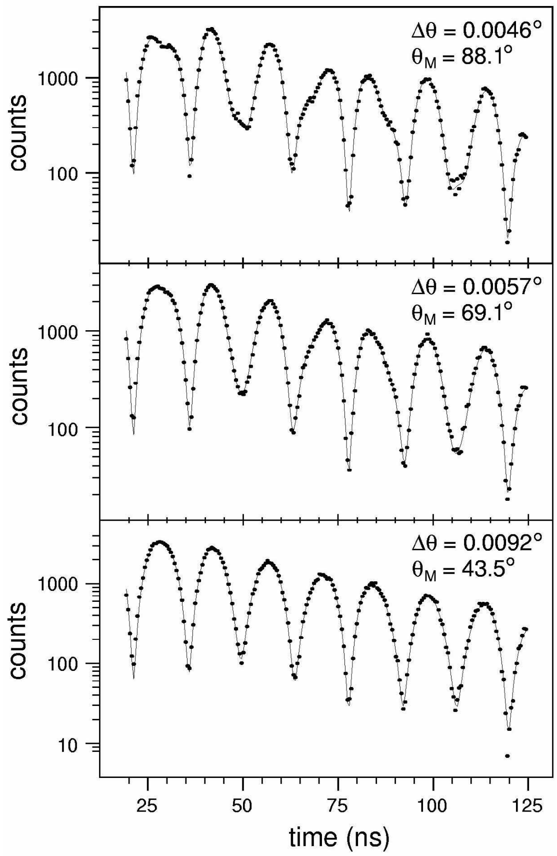

FIG. 2. Experimental time spectra taken at different offset angles Dq. The line represents the theoretical fit to the data by using the software package CONUSS [6]. From the fit, the mixing angle θ_M *is extracted.*

means of nuclear resonant forward scattering from a magnetized Fe foil and reached values as high as 99.9%.

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