Nuclear Resonant Scattering from a $^{57}Fe/C/^{57}Fe$ Thin-film Waveguide

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Introduction

Pulsed synchrotron radiation allows time domain experiments for nuclear resonant scattering. In particular, the time response to nuclear decays for the spatially coherent modes, i.e., for a Bragg reflection[1] or grazing-incidence reflection,[2] has shown the speedup of the coherent decay resulting from the coherent interaction of the radiation with the system of nuclei. We present here the results of nuclear resonant scattering experiment from a x-ray thin-film waveguide consisting of $^{57}Fe/C/^{57}Fe$ layers. In this waveguide, the standing-wave electric field can be resonantly excited at the guided modes inside a carbon layer between thin ^{57}Fe layers and can be emitted directly from the end face of the waveguide in the form of a Fraunhofer diffraction pattern.[3] Therefore, one can expect the guided mode to be a new channel providing the spatially coherent mode for a strong speedup in the time spectrum.

Materials and Methods

We prepared a $^{57}Fe/C/^{57}Fe$ thin-film waveguide for this study. The sample was deposited onto a silicon substrate by sputtering for carbon and MBE-growth for ^{57}Fe layers at the APS deposition laboratory. The quality of the sample for functioning as a x-ray waveguide was checked preliminarily by x-ray reflectivity measurements performed at the SRI-CAT undulator beamline 4-ID. From the best fit to the reflectivity data in Fig. 1, it was found that the average interfacial width is about 8 Å and the layer thicknesses are 47 Å, 359 Å, 120 Å for the ^{57}Fe (top), carbon, and ^{57}Fe (bottom) layers, respectively.

Nuclear resonant scattering measurement at the 14.4125 keV resonance of ^{57}Fe was performed at the SRI-CAT undulator beamline 3-ID, where a highly monochromatic x-ray with an energy bandwidth of about 2 meV is available. Delayed time spectra were taken by an avalanche photodiode (APD) detector with timing electronics synchronized to the bunch pattern in the storage ring. During the nuclear resonant scattering experiment, an external magnetic field of about 0.4 T was applied by a permanent magnet along the sample surface in the scattering plane.

Results and Discussion

For our waveguide, three guided modes (TE0, TE1, and TE2) were found from the dips of reflectivity curve between the critical angles of carbon and iron, as shown in Fig. 1. Part of x-rays beam is not reflected but travels through the guiding layer (i.e., carbon layer) at the guided modes, and the result is reduced intensity in the specular reflectivity. Our sample does not have such a thick slab on the film surface as in Ref. [3] to block the directly reflected x-rays. However, the measured and calculated intensity distribution in Fig. 2, where the incident angle was set to the TE2 guided mode, showed clearly that the Fraunhofer diffraction pattern emitted from the guiding layer can be distinguished from the specular reflection. Figure 3 shows delayed time spectra measured from the specular reflection and the Fraunhofer diffraction due to the guided mode, as indicated by (a) and (b), respectively, in Fig. 2. The time spectrum from the specular reflection shows clearly the speedup of the nuclear decay when compared with the natural decaying time of 140 ns, as shown in Fig. 3(a). Since our sample was magnetized along the beam direction and perpendicular to the linear polarization of the incident x-ray, the quantum beat with its period of about 14 ns due to two allowed M=0 transitions was observed in Fig. 3(a). Faster coherent decay (speedup)

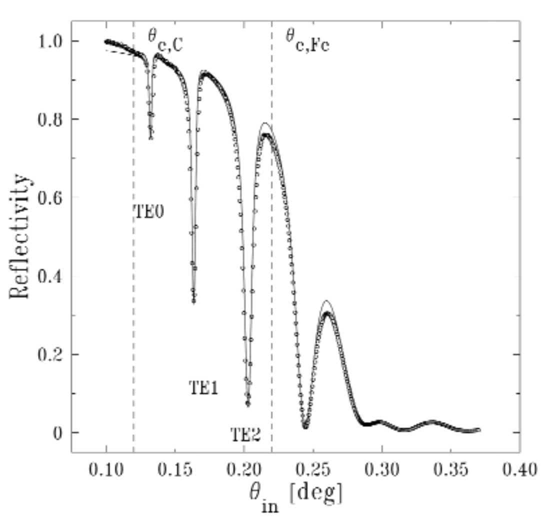

FIG. 1. X-ray specular reflectivity from a 57Fe/C/57Fe thin-film waveguide. Circles represent measurement; the solid line represents the best fit. The dashed lines indicate the critical angles of carbon and iron. The dips correspond to three guided modes, TE0, TE1, and, TE2, respectively.

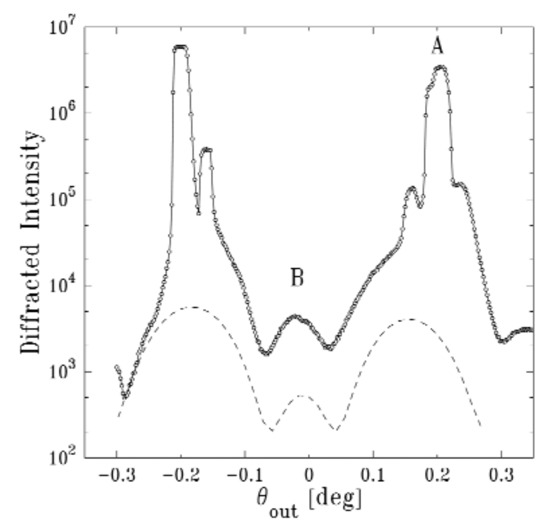

FIG. 2. Diffracted intensities with the incident angle set to the TE2 guided mode. Circles represent measurement; the dashed line represents the calculation of Fraunhofer diffraction intensity. (a): Specular reflection; (b): Fraunhofer diffraction.

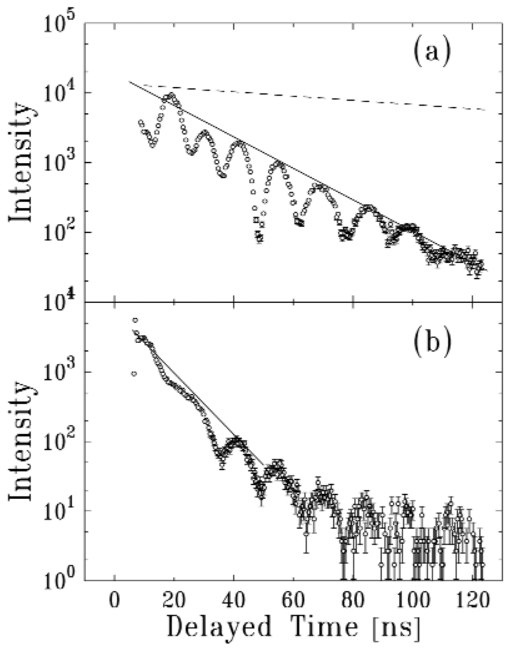

FIG. 3. Delayed time spectra from the specular reflection (a) and the Fraunhofer diffraction (b) at the TE2 guided mode. The dashed line shows a natural exponential decay with a lifetime of 140 ns, and the solid lines show the speedup of coherent decay.

was observed in the time spectrum from the guided mode in Fig. 3(b), in contrast to that observed for the specular reflection. Data analysis using the CONUSS and KGIN programs[4] is in progress to understand the dynamical effect from multiple nuclear and electronic scattering channels at the guided mode.

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