# High Quality Iron Borate Crystal for Nuclear Resonant Scattering Experiment

$^{57}$Fe-enriched $FeBO_3$ single crystal is one of the most advantageous optical elements of the nuclear resonant scattering of synchrotron radiation (SR). Since pure nuclear Bragg scattering (NBS) in the vicinity of Néel temperature $T_N$ can emit an extremely narrow band single-line X-rays on the order of $10^{-8}$ eV [1], this allows one to perform energy domain Mössbauer measurement using excellent SR properties (i.e., polarization, small beam size, etc.). However, high reflectivity and small divergence of NBS are achieved only when the nuclear monochromator crystal has crystallinity on few seconds order. Recently, we have successfully obtained a centimeter-sized very high-quality $^{57}FeBO_3$ single crystal by flux crystal growth [2]. Crystal perfection and magnetic domain structure were investigated by double-crystal topography using a non-dispersive (+,−) setting, i.e., asym-Si(331) × sym-$FeBO_3$ (444). As shown in Fig. 1, the measured rocking curve of $^{57}FeBO_3$ (444) reflection revealed that the value of full width at half maximum (FWHM) was only 4.48 arcsec for $\lambda$ = 1.24 Å. This assures that this $^{57}FeBO_3$ crystal has an ideal crystal perfection suited for an optical element using NBS. Magnetic domain structure was observed using precise X-ray topograph. In the topograph recorded at the peak position, homogeneous X-ray diffraction contrast is obtained from almost the whole of the crystal (see Fig.1 (a)). This indicates that the crystal surface is free from serious lattice defects such as dislocations and inclusions. On the contrary, topographs recorded at low and high-angle positions of FWHM show many straight-line contrasts crossing over the crystal surface (see Figs. 1(b) and 1(c)). The line contrasts are caused by magnetostriction across 90º magnetic domain walls. They are composed many regularly arranged black and white diamond shaped strain sectors with a typical sector size of a few millimeters. Because the black and white contrasts of each sector have been reversed in Figs. 1(b) and 1(c) respectively, it is found that adjacent domains have a slight inclination to the opposite direction of each other with angular misorientation below a few arcsec. These results are the first observation of a unique case showing that regularly arranged multimagnetic domains play a vital role in the high-crystal perfection of $^{57}FeBO_3$.

The optics for the generation of ultrafine monochromatic X-rays at a SR facility are shown in Fig. 2. The experiment was performed at beamline **BL11XU**.

A high-resolution monochromator (HRM) was used for the monochromatization of SR X-ray. Then, the σ-polarized 14.4 keV X-ray of 2.5 meV bandwidth was incident on a $^{57}FeBO_3$ crystal that was mounted in a heater. An external magnetic field of 150 Oe was applied along the $^{57}FeBO_3$ (111) plane to magnetize it

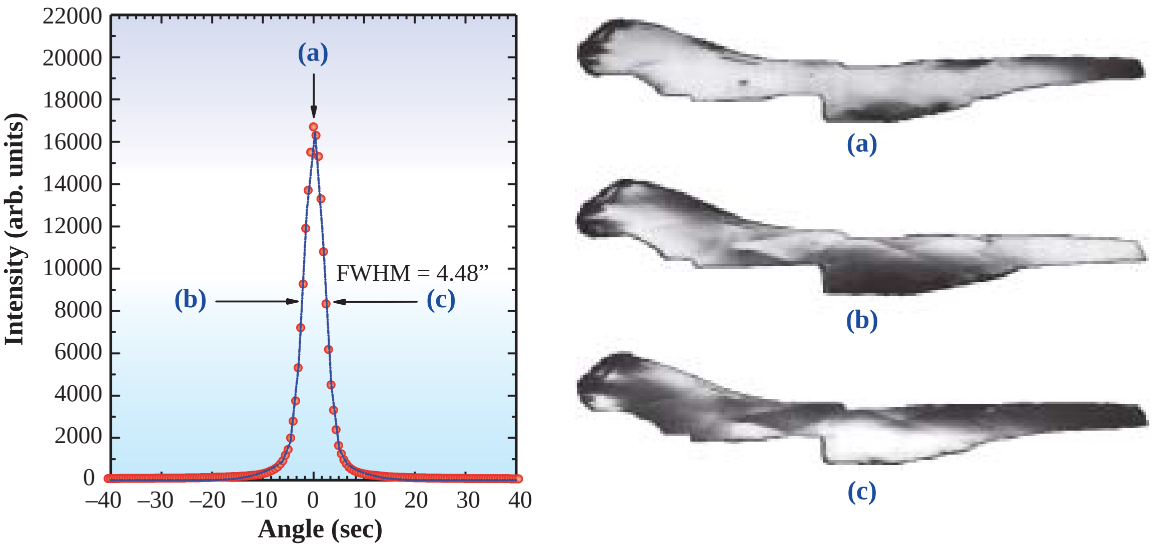


Fig. 1. Rocking curve and X-ray double crystal topograph of $^{57}FeBO_3$ (444) plane with X-ray illumination of whole sample in $H_{ex}$ = 0 Oe. The dashed line is a Gaussian fitting curve. Topographs **(a)**, **(b)** and **(c)** are recorded at the following angles: **(a)** $\Delta\theta$ = 0.0 s, **(b)** $\Delta\theta$ = -2.24 s and **(c)** $\Delta\theta$ = +2.24 s.

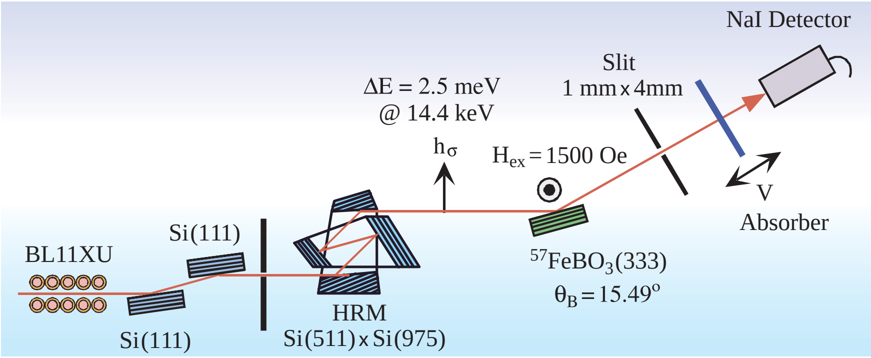


Fig. 2. Optics for ultrafine monochromatization of synchrotron radiation.

perpendicular to the scattering plane. In this optical system, a π-polarized ultrafine monochromatic X-ray beam could be emitted by the electronically forbidden pure nuclear Bragg reflection of $^{57}FeBO_3$ (333).

In Fig. 3, the Mössbauer spectra of a $^{57}$Fe-enriched stainless steel foil are displayed at different temperatures in the range from room temperature up to the Néel temperature. This shows that narrow-band single-line X-rays are obtained at 75.8 deg. From the theoretical fitting on the absorption spectra of thin iron foils, it was estimated that the energy resolution is 15 neV. Intensity and angular divergence were evaluated by measuring a rocking curve of $^{57}FeBO_3$ (333). As the result, their values were 12,000 cps and 3.8 arcsec, respectively (see Fig. 4).

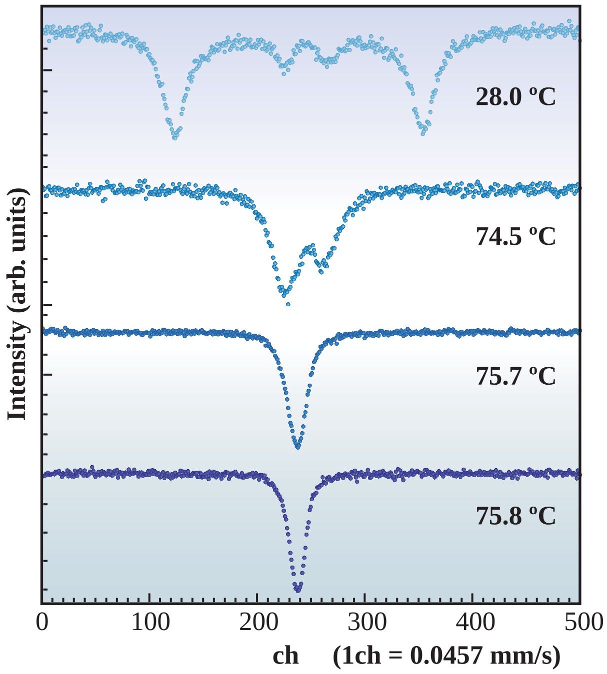


Fig. 3. Mössbauer absorption spectra of 2.5- μm-thick stainless steel foil (90% $^{57}$Fe) measured with reflected Bragg radiation from $^{57}FeBO_3$ (333) at different temperatures.

These results indicate that our obtained ultrafine monochromatized X-ray beam has a very high quality. Therefore, by utilizing an excellent neV bandwidth probe beam, Mössbauer microanalysis, precise γ-ray optics, and other new techniques of SR neV spectroscopy will be greatly advanced.

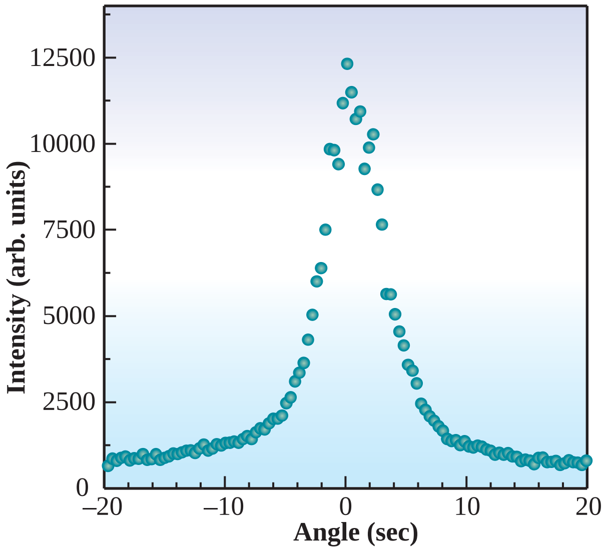


Fig. 4. Rocking curve of NBS from $^{57}FeBO_3$(333) at temperature of T = 75.8 deg.

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## References

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