ELSEVIER

Physica B 241–243 (1998) 1210–1212

PHYSICA B

Laue focusing effect and its applications

V.V. Kvardakov[a,*], V.A. Somenkov[a], J.W. Lynn[b], D.F.R. Mildner[b], H. Chen[b]

[a] *Russian Research Centre "Kurchatov Institute", 123182, Moscow, Russian Federation*
[b] *NIST Center for Neutron Research, NIST, Gaithersburg, MD 20899, USA*

Abstract

The focusing of neutrons by means of symmetric Laue-geometry diffraction from thin perfect crystals has been studied. Applications of the effect to small-angle neutron scattering, single crystal, and powder diffraction experiments have been investigated.

Keywords: Focusing; Perfect crystal; Small-angle scattering; High-resolution diffraction

In recent years there has been continuing interest in new neutron focusing methods and their applications [1–3]. However, some focusing effects that were observed long ago for X-rays [4] have yet to be examined with neutrons. Thus, consider the symmetric Laue-geometry diffraction from a thin crystal. Polychromatic beam emanating through a narrow slit (source) and diffracting by the crystal should be focused in diffraction plane at another line (focus) due to the symmetry of the diffraction geometry, with the focus and the source symmetrically positioned with respect to the crystal plate. The crystal needs to be sufficiently perfect to achieve a fine focal spot. The aim of the present work is to observe the Laue focussing effect in neutron diffraction on perfect crystals. In this case the focus size D_f can be written as

$$D_f = ((D_s)^2 + (2t \sin \theta)^2 + (\Omega L_f)^2))^{1/2}, \qquad (1)$$

where D_s is source (slit) size, t is the crystal thickness, θ is the Bragg angle, Ω is the width of the reflection curve and L_f is the focus distance.

Experiments have been performed with both white and monochromatic ($\Delta\lambda/\lambda \approx 1\%$) beams. For focusing we have used perfect Si crystals ($t \approx 0.3$ mm), and a mosaic $Fe(Si)_{3\%}$ crystals, with slits (0.15–0.5 mm) placed at a distance of 1–2.25 m from the crystal. The diffracted beam was recorded with a neutron Polaroid camera or video radiation detector (14 μm resolution). The typical exposure time for the Polaroid camera with the Si crystal was 10 s–1 min for thermal neutrons and 6–9 min for cold ($\lambda \approx 6.2$ Å) neutrons in the backscattering experiment. For the video radiation detector the exposure time was a few hours.

We found that for film positions closer to the crystal than the focus, the width of the diffracted beam varied approximately linearly, with a minimum value at the focus, and then the width increased for longer distances. For example, with a 0.15 mm slit, the width of the beam immediately

* Corresponding author. Fax: + 7 95 196 59 73; e-mail: kvardakov@imp.kiae.ru (office), V.Kvardakov@g23.relcom.ru (home).

0921-4526/98/$19.00
PII S0921-4526(97)00828-4

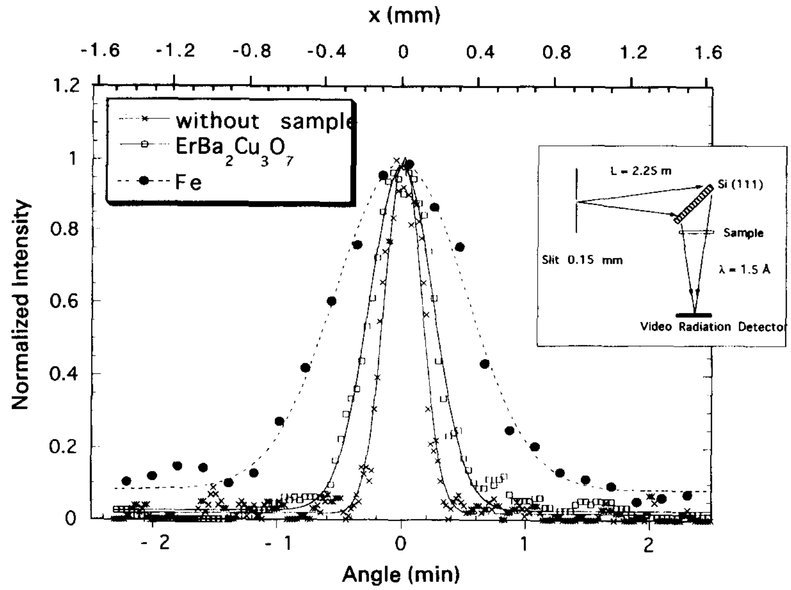

Fig. 1. The resolution curve, SANS on $ErBa_2Cu_3O_7$ single crystal, and SANS on 1 mm thick iron plate.

following the crystal was the projected width of the crystal, 4 cm, but at the symmetric position of 2.25 m the neutrons were focused to a width of 0.23 mm with the perfect Si crystal, and to 3 mm for the $Fe(Si)_{3\%}$ crystal (5′ mosaic), in good agreement with relation (1). The focus size was found to increase with wavelength, but the focusing effect existed up to the angles close to backscattering. Thus, at $2\theta = 173^\circ$ the focused image of the 0.15 mm slit had a 0.8 mm width, whereas the calculated value was 0.6 mm.

Now consider the applications of the effect:

(1) *SANS*: We placed the samples in the diffracted beam just behind the focussing crystal. The small-angle scattering pattern was observed in the crystal focal plane as a broadening of the focus size. The angular resolution of the method can be defined as $\psi = D_f/L_f$. For instance, the experimental resolution was 20″ ($Q = \psi/\lambda \approx 0.6 \times 10^{-5}$ Å^{-1}) for 1.5 Å, $L_s = 2.25$ m, $D_s = 0.15$ mm and 50″ ($Q = 0.5 \times 10^{-5}$ Å^{-1}) for 4.5 Å, $L_s = 1$ m, $D_s = 0.2$ mm. To demonstrate the method we have measured the SANS in 1 mm iron plate and 1 cm thick HTSC $ErBa_2Cu_3O_7$ crystal; the effects were 75″ and 36″, respectively (Fig. 1). 2′–5′ wide SANS was found in Nb–Ti–Cu superconducting wires and in 2–5 mm thick steel industrial plates.

(2) *Single crystal diffraction*: In this case we placed the second slit D_s at the focus point of the first one and rocked the crystal. The width of the rocking curve should be $\Delta\omega \approx ((D_s/L_f)^2 + \Omega^2)^{1/2}$. This value is independent of the wavelength distribution of the beam. So, we can expect that the resolution of single crystal diffraction experiment can be improved (up to the value of the crystal mosaicity) when narrow slits are employed. We have made experiments on a perfect Nd_2CuO_4 crystal on the MOND diffractometer operating in low-resolution mode ($\Delta\lambda/\lambda \approx 3\%$). We placed the slits at the exit of the neutron channel and at the entrance of the counter at the same distance (34 cm) from the crystal. For the symmetric Laue reflections the rocking curve width is reduced from 0.35° to 0.1° and then 0.05° when the slit width was decreased from 7 to 1 mm and then 0.2 mm, respectively. The increase in resolution was at the expense luminosity; a factor of six is lost from 7 to 1 mm, and an additional factor of 10 in going from 1 to 0.2 mm. A resolution of $\Delta d/d \approx 6 \times 10^{-4}$ is achieved with 0.2 mm slits at the diffraction angles higher 50°. For the case of asymmetric Laue reflections (asymmetry angle up to 45°) an improvement in resolution down to 0.1° is also observed with 1 mm slits, but at the larger angles a further

decrease of the slit width does not significantly improve the resolution.

(3) *Powder diffraction*: We placed a thin powder sample in the diffracted beam just behind the focusing crystal. In this case powder diffraction lines are focused too. As a demonstration we have carried out an experiment at $\lambda = 1.5$ Å for the $Fe(Si)_{3\%}$ focussing crystal (0.15° mosaic spread) and graphite sample. The slit D_s was 2 mm wide, and the focus distance L_f was 0.6 m long. The width of the (0 0 2) reflection was measured in a parallel setting with the Polaroid camera at various distances from the crystal. We observed that the width of the line is a minimum at a distance close to 1 m, where the angular width of the line become equal to the crystal mosaicity 0.15°, whereas without focussing it was 0.35°.

In conclusion, Laue focusing is a very simple method that provides an opportunity to carry out SANS experiments, with variable resolution that can approach to the resolution of double perfect crystal spectrometers (but using only one crystal). The method also provides the possibility of improving the resolution of conventional single crystal and powder diffraction instruments.

We thank S.Sh. Shilstein for discussions and V. Sharov for assistance in the work. The work was supported by a grant 97-02-175-88 of the Russian Foundation for Basic Research, COBASE grant of the National Science Foundation and by a NATO Linkage grant HTECH.LG 930549.

References

[1] M.A. Kumakhov, V.A. Sharov, V.V. Kvardakov, SPIE Conf. Proc. 1738 (1992) 368.
[2] D. Mildner, H. Chen, G. Downing, V. Sharov, J. Neut. Res. 1 (1993) 1.
[3] M. Popovici, W.B. Yelon, J. Neut. Res. 3 (1995) 1.
[4] W.L. Bragg, Proc. Camb. Phil. Sos. XVII (1913) 43.