Experimental observation of diffraction focusing of x rays

É. V. Suvorov and V. I. Polovinkina

Institute of Solid State Physics, USSR Academy of Sciences

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Diffraction focusing of the wave field in a doubly diffracted narrowly collimated x-ray beam was observed in experiment. The fine structure of the diffraction beams is revealed in a U-shaped interferometer.

The refractive index of any substance hardly differs from unity in the x-ray band. Therefore, only reflecting lenses are used in x-ray optical systems. Recently however, prospects for the construction of x-ray diffraction lenses have become realistic.[1] Thus, the contraction of an x-ray wave field following double diffraction of a narrowly-collimated beam by a two-crystal interferometer was predicted in[2]. This phenomenon can find application in various x-ray-optics systems. Processes accompanying the separation of wave fields on interfaces and the subsequent interference are of great interest also because they play a decisive role in the formation of the x-ray diffraction image of crystal-lattice defects.[3–7]

A narrow parallel x-ray beam incident on a perfect crystal in the exact Bragg position, unlike a light beam, acquires an angular divergence inside the sample. The wave field is distributed over the entire Borrmann delta with a vertex angle 2θ (θ is the Bragg angle). On the exit surface, the field splits into a transmitted beam E_0 and a reflected beam E_1. In the case of a thin crystal ($\mu t \leqslant 1$) the beam has a width equal to the base of the Borrmann delta

$$\Delta x = 2z\,\mathrm{tg}\,\theta + \delta, \tag{1}$$

where z is the crystal thickness and δ is the width of the primary beam. Inside the Borrmann delta, the wave field is a superposition of transmitted and diffracted waves. The intensity at the exit from the crystal is distributed over Δx in the form of a system of interference fringes. Figure 1 shows a topogram of the diffracted beam E_1. Experiments have shown[8] that the intensity distribution is well described by influence functions of the type

$$g(x,z) = \tfrac{1}{2} I_0 \left[(\chi_H/2)\sqrt{z^2 - x^2}\right]\theta(z)\left[\theta(x+z) - \theta(x-z)\right] \tag{2}$$

for the boundary-value problem considered in[9,10]. Here $I_0(x)$ is a Bessel function of zero order, χ_H is the polarizability of the crystal, $\theta(z)$ is the Heaviside step function, and x and z are the normalized coordinates in the scattering plane.[1]

If such a beam is diffracted again by a crystal identical to the first crystal then, as predicted in[2], the field should contract to the initial width δ of the incident beam.

In this study we obtained experimentally and investigated for the first time the fine structure of diffracted beams in a U-shaped interferometer for the case of a narrowly-collimated incident beam. The interferometer crystal was cut out from dislocation-free silicon perpendicular to the $\{111\}$ growth axis and was polished

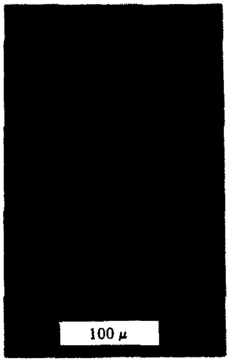

FIG. 1. Distribution of the intensity in the diffracted beam [reflection (224), $z = 452\ \mu$, $\delta = 10\ \mu$, MoK_α radiation].

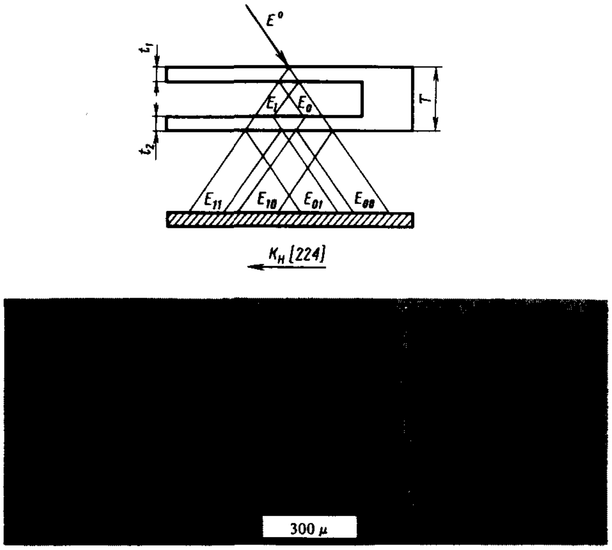

FIG. 2. a) Geometry of interferometer. b) Topograms of the beams E_{11}, E_{10}, and E_{01} [reflection (224), MoK_α radiation].

mechanically and chemically. The crystal dimensions and the geometry are shown in Fig. 2a. The photographs were taken with an A-3 camera and a Rigaku Denky RU-3HM x-ray apparatus using MoK_α radiation. Figure 2b shows the intensity distribution in the beams E_{11}, E_{01}, and E_{10}, where E_{11} is the beam diffracted in the first crystal and passing through the second, E_{10} to the contrary is the beam reflected in the first crystal and passing through the second crystal, and finally E_{01} is the beam reflected in both crystals. The intensity in the E_{11} beam increases in oscillatory manner in the direction of the diffraction vector $\mathbf{k}_H$, and the intensity in E_{10} decreases correspondingly. In the center of the Borrmann delta, both beams have an intensity maximum of approximate width 20 μ.

The doubly-diffracted beam has a bright maximum at the center (focused in the reflection plane), and weak oscillations (smaller by several orders of magnitude than the central peak) over the entire beam. The central maximum of approximate width 20 μ is accompanied by two weaker peaks (in Fig. 2b they are merged with the principal peak).

The general character of the intensity distributions in E_{11}, E_{10}, and E_{01} agrees with that predicted in[2], but the experimentally observed picture is more complicated. The central peak on all the topograms is accompanied by satellites, and this leads to a noticeable broadening of the peaks on the photographs of Fig. 2b, since the topograms are made excessively contrasty for the purpose of revealing the fine structure. The appearance of additional peaks may be due to variation in the plate thickness (the accuracy with which the interferometer is constructed is limited), to the inhomogeneity of the impurity distribution over the volume of the crystal, etc.

The topograms, and especially the microphotometry plots, reveal in addition to the extinction oscillations also noticeable large-period beats. This effect may be connected with the beats of the intensity in the beams E_0 and E_1 (see Fig. 1), which are due to the absence of predominant polarization in the primary beam E^0.[8,11]

Our experiment confirms the main results predicted in[2], particularly the appearance of diffraction focusing in a doubly diffracted beam. Further research is necessary, however, in order to understand a number of the details of the fine structure of the images.

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