Observation of the focusing of x rays diffracted by a perfect crystal

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Diffraction focusing of a weakly absorbed wave field was obtained for the first time ever under conditions of a large distance between the radiation source and the observation plane. Singularities not observable on ordinary section topograms were observed on the images of wedge-shaped crystals.

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Methods of x-ray topography are usually employed at short distances ($L < 0.5$ m) between the source of a spherical wave and the plane of observation of the diffraction pattern. The details of the images of perfect crystals are described in these cases by the Kato theory.[1] Afans'ev and Kon[2] have considered theoretically the formation of the image at large distances L and have predicted a new phenomenon—the focusing of a weakly absorbed wave field, observable at a definite relation between the quantity $L = L_s$ and the crystal thickness $t = t_s$. For symmetrical Laue reflection this relation is of the form

$$L_s = K_s t_s = \frac{\sin^2 2\theta}{2\cos\theta |\chi_{rh}| C} t_s , \tag{1}$$

where θ is the Bragg angle, C is the polarization factor, and χ_{rh} is the real part of the Fourier component of the polarizability.

We report here an experimental investigation of the diffraction pattern at large distances L. The experimental setup is shown in Fig. 1. The x-ray source was the

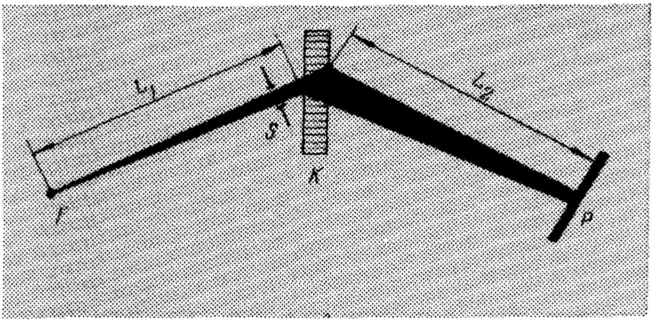

FIG. 1.

Microflex apparatus with focus dimension not larger than 20 μm. We used a copper-anode radiation. A slit S separated the spectral line $K\alpha_1(\alpha = 1.54$ Å). The image was focused in the P plane on photographic plates of MR type. The exposure time was 5–20 hours. We investigated the diffraction pattern obtained from wedge-shaped Ge single crystals at a fixed distance $L = L_1 + L_2 = 2$ m. The use of the wedge shape enabled us to observe on a single topogram the image produced both under focusing conditions ($t = t_s$) and at other crystal thicknesses. We obtained sectional topograms of the symmetrical Laue reflections (333), (220), and (111) at $L_1 = L_2$. This geometry ensured chromatic focusing of the $K\alpha_1$ line. Under the specified experimental conditions the values of θ, K_s, and t_s were the following: for the reflection (333)–$\theta = 45.1°$, $K_s = 4.63 \times 10^4$, $t_s = 50\ \mu$m, for the reflection (220)–$\theta = 22.7°$, $K_s = 1.18 \times 10^4$, $t_s = 170$ μm, and for the reflection (111)–$\theta = 13.6°$, $K_s = 0.63 \times 10^4$, $t_s = 316\ \mu$m. The choice of the reflection was governed by the fact that the topographic images of each of them are formed by different wave fields propagating in the crystal. The (333) image is formed by weakly and strongly absorbed fields of σ polarization (the polarization factor for the π-polarization waves is close to zero; the absorption coefficients μ_1 and μ_2 of the weakly and strongly absorbed fields differ by only a factor of four and at $t = t_s$ we have $\mu_1 t_s = 0.7\ \mu$m, $\mu_2 t_s = 2.8\ \mu$m. The (220) reflection is formed only by a weakly absorbed σ-polarization field (for the waves of this field $\mu_2 \approx 50\,\mu_1$, and the π-polarization waves are much more strongly absorbed). All the wave fields contribute to the (111) image at $t \leqslant 200\ \mu$m.

Figure 2 shows the sectional topograms of the reflections (220) and (333) as well as the photometric curves of three sections of the topograms: at $t \to 0$, $t = t_s$, $t > t_s$. It is seen that the wedge shape of the crystal is not duplicated in the images, as is the case of the sectional topograms at $L < 0.5$ m.[3] Both reflections have a smeared-out broad image in the region of the sharp edge of the wedge ($t \to 0$); with increasing thickness of the sample, its image contracts in the scattering plane and has a minimal width when the condition (1) is satisfied. Further increase of the crystal thickness leads to broadening of the image.

The width of the image (Δx) at $t = t_s$ is in both cases of the order of 30 μm, whereas theoretical estimates yield $\Delta x = 1.4\ \mu$m for (220) and $\Delta x = 1.6\ \mu$m for (333).[2] The large width of the focused image is probably due to the insufficient linear resolu-

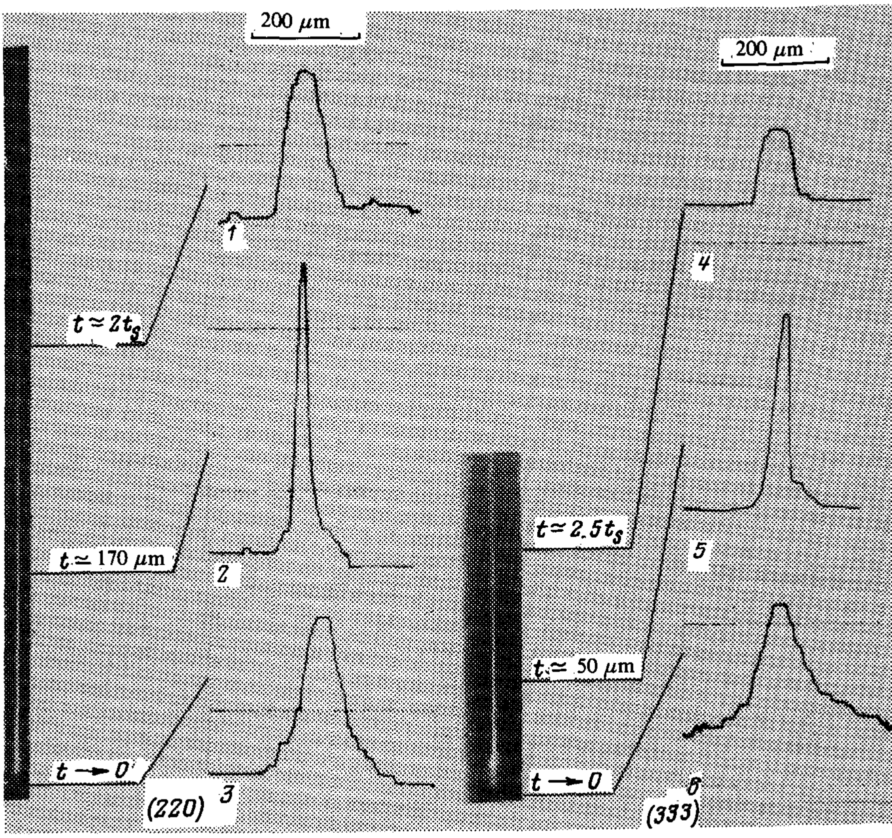

FIG. 2.

tion which is limited by the following: the dimensions of the source focus, the deviation of the reflecting plane from the symmetrical Laue position, and the mechanical instability of the system during the exposure time. In addition, theoretical estimates made in the approximation of a strongly absorbing crystal seem to underestimate the value of Δx.

The images of a thin crystal ($\mu t \lesssim 1$) reveal intensity oscillations due to the interference of strongly and weakly absorbing wave fields. This effect is particularly clearly observed in the (111) reflection. Figure 3 shows a fragment of the (111) topogram, corresponding to the section of the crystal near the tip of the wedge ($t < t_s$). It is seen that the pattern of the pendulum contours differs from that observed on the sectional topograms at $L < 0.5$ m,[1,3] namely: the equal-intensity contours are directed with their vertices not to the tip of the wedge, but to the base.

The foregoing experiments have shown that the form of the diffraction pattern depends substantially on the distance L. At the values of L_s and t_s connected by formula (1), the weakly absorbed field is focused in the distance plane. The interfer-

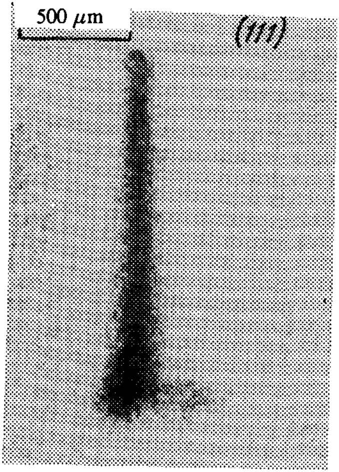

FIG. 3.

ence bands of the pendulum solution at $t < t_s$ have a curvature opposite that predicted by the Kato theory. It follows from the results that further theoretical and experimental research on x-ray diffraction is necessary.

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