Observation of anomaly in angular distribution of parametric x-ray scattering

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(Submitted 5 December 1989; resubmitted 24 January 1990)
Pis'ma Zh. Eksp. Teor. Fiz. **51**, No. 4, 213–215 (25 February 1990)

A strong, narrow peak due to a multiwave emission mechanism has been observed in the angular distribution of parametric x radiation. The intensity and angular width of this peak are determined and compared with those in the case of the two-wave mechanism.

A charged particle moving at a constant velocity through a homogeneous medium cannot emit in the x-ray range, since the refractive index of the medium is less than unity in this case. In a crystal, however, under conditions of dynamic diffraction of the emitted photons, the inequality

$$n(\alpha, \omega) \geqslant 1, \tag{1}$$

may hold, and as a result, a parametric x-ray emission will arise. Here n is the refractive index of the medium, ω is the frequency of the parametrically emitted x ray, the parameter $\alpha = [(2\mathbf{k}\vec{\tau} + \vec{\tau}^2)/\mathbf{k}^2]$ is the deviation from the exact Bragg condition, $\mathbf{k}$ is the wave vector of this x ray, and $\vec{\tau}$ is a reciprocal lattice vector of the crystal. In the case of two-wave diffraction, emission condition (1) holds far from the point at which the Bragg condition holds ($\alpha = 0$), and the amplitude of the diffracted wave is quite small. The parametrically emitted x rays detected in the diffraction direction propagate in a narrow cone with a vertex angle $\Delta\theta \sim \sqrt{\gamma^{-2} + |\chi_0'}$, and have an energy spread $(\Delta\omega/\omega) \sim \sqrt{\gamma^{-2} + |\chi_0'|}$, where γ is the Lorentz factor of the charged particle, and χ_0' is the real part of the polarizability of the crystal.[1]

 0021-3640/90/040242-04$01.00

The research on parametric x radiation has taken the direction of a search for entities in which the emission yield is maximized. A promising entity is the GaAs single crystal.[2] As was pointed out previously,[1] an important role is played in this emission by effects which arise during multiwave diffraction of the x rays that are formed, i.e., in a regime of multiwave emission, which was recently observed experimentally.[3] The spectrum and angular distribution of parametric x-ray emission depend on the effective refractive index in the crystal and on the absorption length (which is inversely proportional to the linear absorption coefficient). Under multiwave diffraction conditions, inequality (1) holds for some of the refractive indices of the crystal closer to the point $\alpha = 0$. The amplitudes of the diffracted waves may be substantially higher than in the two-wave case. In addition, the linear absorption coefficient may decrease substantially in the multiwave emission geometry.[4] In view of the relatively small angular and energy spreads of the x rays, we might thus expect that the multiwave emission regime would result in a significant change (increase) in the angular density of the parametric x-ray emission in a narrow angular interval $\sim\sqrt{|\chi_\tau|}$, where χ_τ is a Fourier component of the expansion of the polarizability of the crystal in reciprocal lattice vectors.

In this letter we report a study of the angular distributions of the parametric x-ray emission which arises in a GaAs crystal during the passage of 900-MeV electrons. We find that against the background of the ordinary two-wave distribution there is a narrow peak due to multiwave emission. We compare the angular half-widths and intensities of the two-wave distribution and the multiwave peak.

The experiments were carried out on the Tomsk synchrotron. A GaAs single crystal 400 μm thick was held in a goniometer in such a way that the electrons moved in a direction nearly along the $\langle \bar{1}\bar{1}0 \rangle$ crystallographic axis. In this particular geometry, degenerate eight-ray (000) (022) (02$\bar{2}$) (040) (202) (20$\bar{2}$) (400) emission is

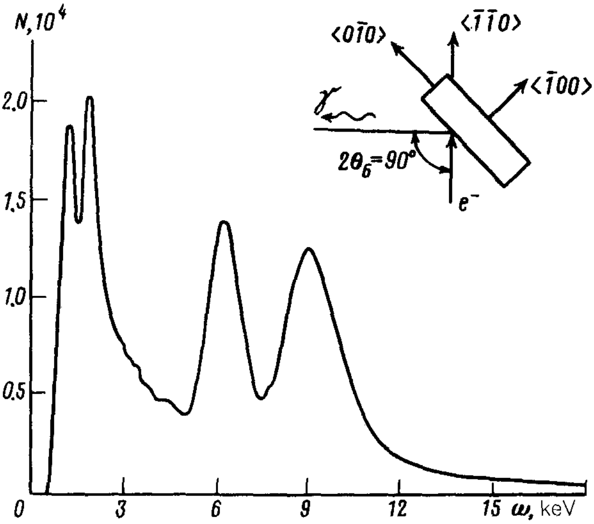

FIG. 1. Spectrum of parametric x-ray emission by 900-MeV electrons for the case of emission at (400) planes in GaAs. The inset shows the experimental geometry.

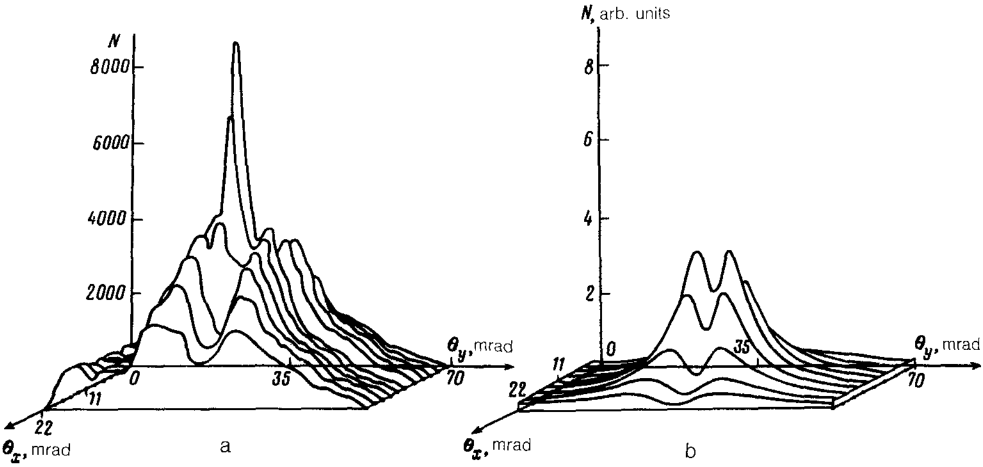

FIG. 2. Angular distributions of the parametric x-ray emission by 900-MeV electrons in GaAs. a—Experimental distributions for conditions corresponding to multiwave emission; b—theoretical distributions for two-wave emission of the (400) reflection.

excited for an x-ray energy of 6.2 keV; i.e., the two four-ray cases (000), (022) $(02\bar{2})$ (040) and (000) (202) $(20\bar{2})$ (400) "work" simultaneously. The emission was detected at the angle $2\theta_B = 90°$ in the direction of the (400) two-wave reflection with an RKD-1 linear coordinate proportional detector with a 2×50 mm window and a spatial resolution of 200 μm. The detector was moved at steps of 2 mm in the horizontal direction in the plane perpendicular to the wave vector of the emitted x rays. The distance from the crystal to the detector window was 710 mm.

Figure 1 shows a typical emission spectrum. We can clearly distinguish a peak in the parametric x radiation with an energy of 6.4 ± 0.6 keV and a characteristic-emission peak at an energy of 9.3 ± 0.9 keV. The inset in Fig. 1 shows the experimental geometry. In the measurements of the angular distributions of the parametric x radiation, the discriminator thresholds were chosen in such a way that the only x rays which would be detected were those whose energies fell in the peak of parametric x radiation. Figure 2(a) shows the angular distributions of the parametric emission measured at steps of 2.8 mrad along the θ_x axis. Figure 2(b) shows angular distributions derived theoretically for the case of two-wave emission.[5] On the whole, the two distributions agree qualitatively, except at the center of the reflection, where the experimental distributions exhibit a clearly defined peak due to the multiwave mechanism for the parametric x-ray emission. The emission intensity in the peak is higher by a factor of 2.5, and the angular width of the peak is smaller by a factor of 4, than the corresponding result for the (400) main reflection of parametric x-ray emission in the case of two-wave emission.

These results show that the multiwave emission regime can indeed lead to an increase in the spectral and angular density of the parametric x-ray emission and that multiwave emission holds promise for the development of sources of quasimonochromatic x radiation.

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Translated by Dave Parsons