Effect of axial orientation of the sample on the angular distribution of the γ radiation emitted by relativistic electrons in single crystals

M. Yu. Andreyashkin, S. A. Vorob'ev, V. N. Zabaev, A. P. Kashirin,
G. A. Naumenko, A. P. Potylitsyn, and V. M. Tarasov
Scientific-Research Institute of Nuclear Physics, S. M. Kirov Tomsk Polytechnical Institute, 634061, Tomsk

(Submitted 18 February 1991)
Pis'ma Zh. Eksp. Teor. Fiz. **53**, No. 9, 474–476 (10 May 1991)

The change caused in the angular distribution of the γ radiation emitted by 900-MeV electrons in Si and diamond single crystals by a switch from a random orientation of the crystal to an axial orientation has been studied experimentally. A fundamental difference between the behavior of the hard spectral component and that of the soft components has been discovered.

In the course of a switch from a random orientation of diamond and silicon crystals to an axial orientation in experiments at the Tomsk synchrotron in 1979, it was observed that the cone of the soft component of the γ radiation emitted by electrons became narrower.[1] This result was subsequently confirmed in Refs. 2 and 3. At the same time, other experiments indicate that the mean square multiple-scattering angle θ_0 increases for relativistic electrons which intersect a crystal along an axial direction.[4,5] These facts, which appear at first glance to be contradictory, can all be explained by the following simple mechanism.

As a flux of electrons strikes a crystal in a direction along a crystallographic axis, the electrons become redistributed into two groups, depending on the impact parameter. The first group consists of the particles which are captured in a regime of bound or quasibound motion. The emission by these particles forms the so-called channeling-radiation peak in the soft part of the spectrum (Fig. 1). The angular distribution of the channeling radiation is determined by the critical channeling angle ψ_L.

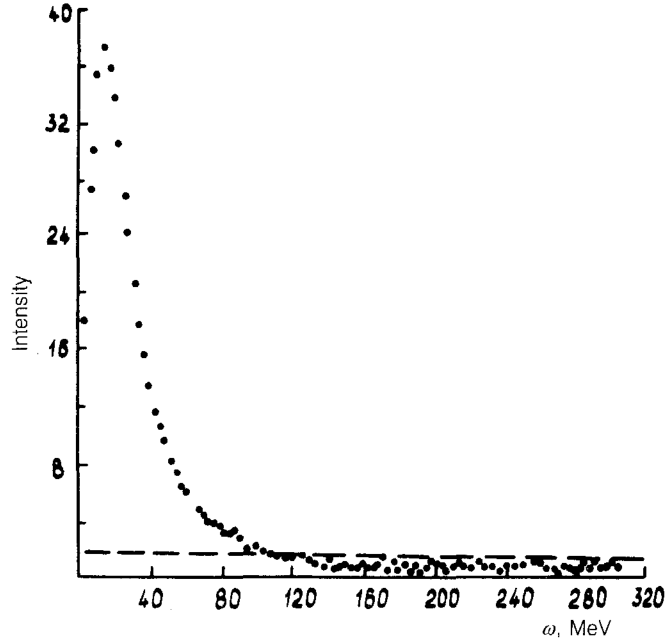

FIG. 1. Spectrum of the γ radiation emitted by electrons in a diamond crystal. Points—Axial orientation; dashed line—random orientation.

The second, and larger, group is made up of above-barrier particles, which generate a coherent bremsstrahlung. This mechanism is predominant in the hard part of the spectrum, at photon energies $\omega > 100$ MeV (Fig. 1). The angular distribution of the emission from the above-barrier particles depends on the mean square multiple-scattering θ_0, which increases when the crystal reaches an axial orientation.[4,5]

It follows that for sufficiently thick crystals, under the condition $\theta_0 > \psi_L$, there should be a fundamental difference between the angular distributions of the soft component (the peak region) and the hard component (the tail) of the γ-ray spectrum. When the crystal is in an axial orientation, the angular distribution of hard photons expands as a result of the increase in the angle θ_0, while that of the soft photons contracts, in correlation with the value of the angle ψ_L.

These suggestions regarding the behavior of the electrons in oriented crystals have been tested experimentally at the Tomsk electron synchrotron. The key parts of the detector apparatus were a NaI(Tl) total-absorption γ spectrometer and a set of coordinate wire chambers. The characteristics of the apparatus and the procedure are described in Refs. 6 and 7.

Figure 1 shows the γ-ray emission spectrum measured for a diamond crystal at an electron energy $E_0 = 900$ MeV, a detection threshold $\omega_{\text{thr}} = 2$ MeV, a γ collimation angle $\theta_c = 0.6 \times 10^{-3}$ rad, a crystal thickness $t = 0.35$ mm, and a $\langle 100 \rangle$-axis orientation. Shown for comparison in Fig. 1 is a spectrum measured for a disoriented target.

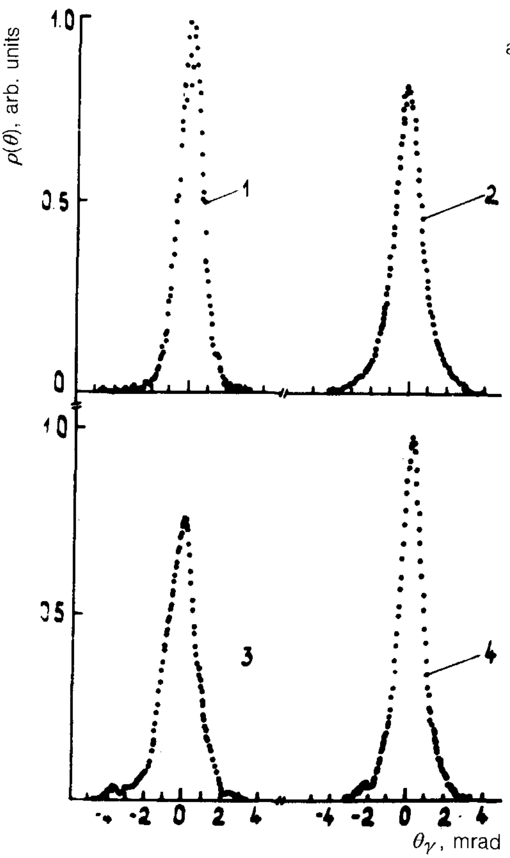

FIG. 2. Projected angular distributions of the γ radiation emitted by electrons in a diamond crystal. a—$\omega < 80$ MeV; b—$\omega = 120$–300 MeV. 1, 3) ⟨100⟩ axis; 2, 4) random.

Under the specified conditions, the critical channeling angle and the multiple-scattering angle (for the amorphous analog of diamond) are $\psi_L = 0.47\times10^{-3}$ rad and $\theta_0 = 0.9\times10^{-3}$ rad, respectively. In other words, the condition $\theta_0 > \psi_L$ holds. Figure 2 shows projected angular distributions of the γ-ray emission for two energy ranges. The histograms have been normalized by area.

Corresponding measurements were carried out on a silicon single crystal ($t = 0.37$ mm, ⟨100⟩). Table I shows $\eta = \sigma_{\langle\ \rangle}/\sigma_{\text{rand}}$, the coefficient of the relative change in the widths of the angular distributions, where $\sigma_{\langle\ \rangle}$ and σ_{rand} are the mean-square deviations for the axial and random orientations of the crystals. The statistical errors in these quantities are $\Delta\sigma \simeq 6$–8%.

A broadening of the hard component of the γ-ray emission in a Si crystal ($\eta = 1.42$) corresponds to an increase in the angle θ_0 ($\eta = 1.5$) detected at an electron energy of 1200 MeV in Ref. 5.

These results are evidence that the two components of the γ radiation emitted by the electrons do indeed behave differently in the transition from a random orientation

TABLE I.

Target orientation	Energy range, MeV		
	< 80	120 - 900	120 - 300
Diamond, ⟨110⟩	0,74	-	1,31
Si< 100 >	0,75	1,42	-

of a crystal to an axial orientation. We believe that this fact improves our understanding and interpretation of various pieces of experimental data on the dynamics and emission of electrons in crystals.

In particular, it has been reported in several experimental papers that the yield of extremely high-energy γ rays is lower in various crystals when the crystals are oriented than when they are disoriented (see Fig. 1; see also Refs. 8 and 9). This effect has been discussed in the literature, but it has not been definitively resolved.[10,11] The expansion of the cone observed experimentally by us, in which the hard photons are emitted, makes it possible to explain the suppression as resulting from a collimation of the γ-ray emission which occurred in those experiments.

We thank B. N. Kalinin for useful discussions.

[1] Yu. N. Adishchev, P. S. Anan'in, S. A. Vorob'ev *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **30**, 430 (1979) [JETP Lett. **30**, 402 (1979)].

[2] N. I. Lapin, V. I. Kasilev, and S. F. Shcherbak, Ukr. Fiz. Zh. **30**, 1155 (1985).

[3] A. I. Aleĭnik, S. A. Vorob'ev, B. N. Kalinin *et al.*, Zh. Tekh. Fiz. **56**, 1416 (1986) [Sov. Phys. Tech. Phys. **31**, 838 (1986)].

[4] A. P. Antipenko, N. G. Afanas'ev, A. V. Gann *et al.*, Yad. Fiz. **44**, 1585 (1986) [Sov. J. Nucl. Phys. **44**, 1030 (1986)].

[5] A. P. Antipenko, S. I. Blazhevich, G. L. Bochek *et al.*, in *Proceedings of the Eighteenth All-Union Conference on the Physics of the Interaction of Charged Particles with Crystals*, Izd. MGU, Moscow, 1989, p. 96.

[6] M. Yu. Andreyashkin, V. N. Zabaev, A. P. Kashirin *et al.*, in *Abstracts, Third-All Union Conference on Radiation Emitted by Relativistic Particles in Crystals*, Nal'chik, 1988, p. 95.

[7] M. Yu. Andreyashkin, V. N. Zabaev, B. N. Kalinin *et al.*, Prib. Tekh. Eksp., No. 6, 55 (1989).

[8] A. N. Didenko, V. N. Zabaev, B. N. Kalinin *et al.*, Phys. Lett. A **82**, 54 (1981).

[9] M. Yu. Andreyashkin, I. E. Vnukov, S. A. Vorob'ev *et al.*, Dokl. Akad. Nauk SSSR **307**(8), 1358 (1989) [Sov. Phys. Dokl. **34**, 717 (1989)].

[10] D. I. Gruev and M. A. Kumakhov, Pis'ma Zh. Tekh. Fiz. **11**, 1245 (1985) [Sov. Tech. Phys. Lett. **11**, 514 (1985)].

[11] V. A. Bazylev, V. V. Golovizini, and A. V. Demura, Zh. Eksp. Teor. Fiz. **92**, 1946 (1987) [Sov. Phys. JETP **65**, 1093 (1987)].

Translated by D. Parsons