Comparison of a coherent bremsstrahlung spectrum and a radiation spectrum produced by axial electron channeling in a diamond single crystal

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The evolution with a crystal orientation of γ-radiation spectra of channeled electrons with an energy $E = 870$ MeV was experimentally observed for the first time in a $\langle 110 \rangle$ diamond with a thickness $t = 0.35$ mm. The results obtained define the regions of crystal orientation angles within which the coherent bremsstrahlung effect or the radiation due to channeling occurs.

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The spectral characteristics of coherent bremsstrahlung (CBS) and the recently discovered radiation due to channeling (CR) of relativistic electrons in single crystals were compared in the theoretical papers.[1-3] Such comparison makes it possible to determine the regions of photon energies and crystal orientation angles for which the generation of electromagnetic radiation proceeds preferentially via either one of the two mechanisms that complement each other in the overall picture of γ radiation. This paper is devoted to an experimental determination of the influence on the radiation spectral characteristics of the initial incidence angle of an electron beam with an energy $E = 870$ MeV relative to the $\langle 110 \rangle$ axis of a diamond single crystal with a thickness $t = 0.35$ mm. This problem has been comprehensively investigated for CBS, but experimental data for the evolution of γ ray spectrum with a crystal orientation are not available for CR. This complicates the understanding of the radiation mechanism for electron channeling and the prospects for its practical use.

The experiment was performed using an internal electron beam of the Tomsk synchrotron (monochromaticity $\Delta E/E \lesssim 0.5\%$, divergence $\Delta\theta_e \approx 10^{-4}$ rad).[4] The intensity spectrum for photon energies $\omega = 8$–1000 MeV was measured by using a pair magnetic γ-spectrometer whose characteristics (energy resolution and efficiency) were calculated by using the Monte Carlo method. The spectrometer resolution, $\Delta\omega/\omega = 1.2\%$ for $\omega = 10$ MeV, improved with increasing photon energy. For $\omega = 800$ MeV, for example, $\Delta\omega/\omega = 0.8\%$. The energy dependence of the spectrometer efficiency was measured experimentally for a γ-ray beam with a known spectrum (Schiff), which was obtained by decelerating the electrons in amorphous targets -- graphite and tantalum. The experimental results are in good agreement with the calculation. The photon yield N_γ, normalized to a unit accelerated current, was measured in the experiment for the following orientations of the electron beam relative to the $\langle 110\rangle$ crystal axis: $\psi_b = 0$, 0.5, 1.5, 2.9, and 5.9 mrad; in all the cases the electron momentum was in the (001) plane, i.e., the rotation angle of the crystal relative to the other axis of the goniometer was $\psi_g = 0$.

Figure 1 shows the ratio $\eta(\omega) = N_{\gamma i}/N_{\gamma x}$ of the yield of photons with an energy ω for the first four orientations of the photon yield from a completely disoriented target. It should be noted that the radiation spectrum obtained for "chaotic" orientation ($\psi_b = 150$ mrad, $\psi_g = 8.5$ mrad) in the region $\omega \lesssim 200$ MeV is almost identical to the spectrum for the amorphous target. We can see from curve 1 in Fig. 1a that the radiation intensity at small energies $\omega \lesssim 20$ MeV in the case of axial channeling greatly exceeds the radiation intensity in a disoriented diamond ($\eta_{\max} = 36$). However, for hard photons with $140 \leqslant \omega \leqslant 870$ MeV the radiation intensity is lower than that from a disoriented target ($\eta_{\min} = 0.4$) and remains small for diamond disorientations $\psi_b = 0.5$ and 1.5 mrad. A crystal disorientation by angles $\psi_b = 0.5$ and 1.5 mrad, which is greater than the critical angle of axial channeling ($\psi_c \approx 0.4$ mrad), greatly decreases the γ-ray yield in the region $\omega \lesssim 20$ MeV, whereas the yield changes negligibly in the

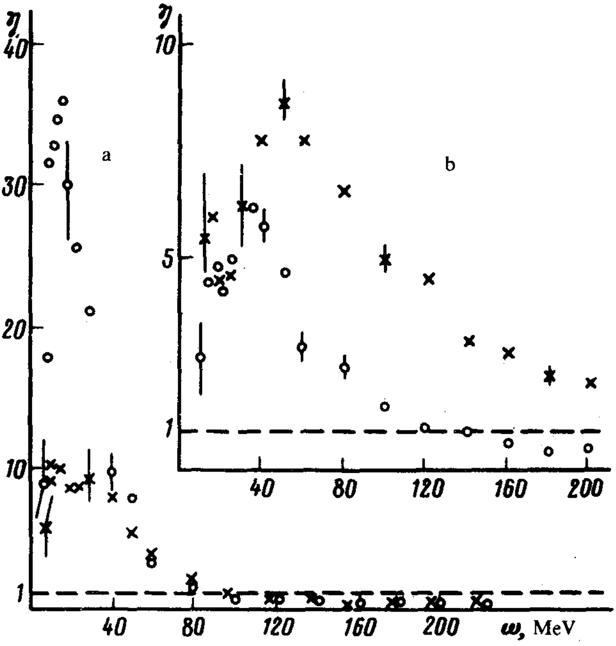

FIG. 1. (a) Spectral distributions of the relative radiation intensity $\eta(\omega)$ for diamond crystal orientations $\psi_g = \psi_b = 0$ mrad (points) and $\psi_g = 0, \psi_b = 0.5$ mrad (crosses); (b) spectral distributions of the relative radiation intensity $\eta(\omega)$ for diamond crystal orientations $\psi_g = 0$ mrad, $\psi_b = 1.5$ mrad (points) and $\psi_g = 0$ mrad, $\psi_b = 2.9$ mrad (crosses).

harder part of the spectrum $\omega \geqslant 30$ MeV. In addition, the shape of the spectrum changes insignificantly as a result of varying the electron arrival angle from 0.5 to 1.5 mrad. This contradicts CBS theory, according to which the location of the first maximum in the spectrum depends almost linearly on the ω disorientation angle. For a disorientation $\psi_b = 2.9$ mrad (Fig. 1b) the maximum in the spectrum is in satisfactory agreement with the calculated value of $\omega_0 = 70$ MeV obtained from CBS theory.[5,6] In this case we have $\eta_{\min} > 1$ in the energy region $\omega > 140$ MeV. This also indicates that the CBS mechanism is valid for the specified orientation.

We can see from the results obtained that the intense peak in the spectral region $\omega \leqslant 20$ MeV (Fig. 1a) is caused primarily by electrons captured in the subbarrier states (for $\psi_b \leqslant \psi_c$), and the contribution of the above-the-barrier particles to the radiation is the controlling factor in a broader angular region ($\psi_b \leqslant 4\psi_c$), i.e., it is appreciable only when the crystal, in which the particles are moving in the transitional channeling regime (intermediate regime between the axial and the plane), is tilted. This contribution is also in effect when the axial-channeling regime is vigorously satisfied,

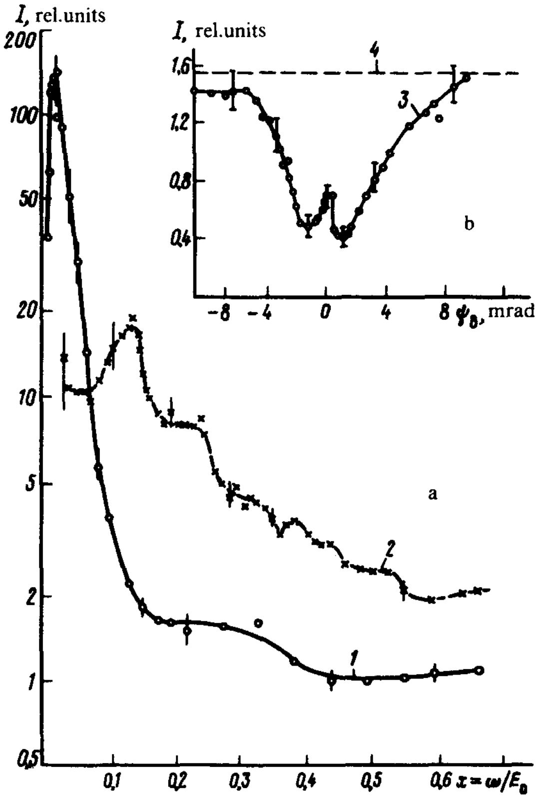

FIG. 2. (a) Spectral distributions of the radiation intensity $I(\omega)$ for diamond crystal orientations $\psi_g = 0$ mrad, $\psi_b = 0$ (points) and $\psi_g = 0$ mrad, $\psi_b = 5.9$ mrad (crosses); (b) orientational dependence of the radiation intensity for a photon energy $\omega = 600$ MeV.

$\psi_b = \psi_g = 0$, because of angular divergence of the electron beam, dechanneling, etc., which can lead to a broadening of the maximum in the spectral distribution of channeling radiation.

The intensity spectra for CR (curve 1 for the orientation $\psi_b = \psi_g = 0$) and CBS (curve 2, $\psi_g = 0$, $\psi_b = 5.9$ mrad) are shown in Fig. 2. The maxima, whose location is in good agreement with the calculated values of Refs. 5 and 6, are observed in the CBS spectrum. The yield of hard photons ($\omega > 140$ MeV) in this case is much higher than that when the channeling condition is satisfied. This contradicts the data of Ref. 7, where an increase in the yield of photons with energies $\omega/E = 0.2$–0.8 (for $E = 1$ GeV) was observed for zero arrival angles of electrons relative to the $\langle 111 \rangle$ axis, as compared with a disoriented crystal. In our opinion, this is due to uncertainties in normalization of the experimental data in Ref. 7. We measured the orientational dependences of the yield of γ quanta with an energy $\omega \geqslant 400$ MeV for $\psi_g = 0$. A typical curve is shown in Fig. 2b. A similar dependence was observed earlier,[8] but without a central maximum. An increase in the γ quanta yield was obtained under axial-channeling conditions and in a relatively low-energy region $\omega/E = 0.2$–0.3.[9] It should be noted that the central maximum on the curve in Fig. 2b is almost twice as narrow as that for the orientational dependences of the yield of γ quanta with an energy $\omega = 20$ MeV and the total energy of γ radiation.[10] A broadening of the orientational maxima for $\omega = 20$ MeV and the total energy yield are caused by spontaneous radiation due to transitional channeling. The shape of the orientational dependence of γ quanta with $\omega \geqslant 600$ MeV can be accounted for primarily by the influence of the evolution of the electron flux in the single crystal on the bremsstrahlung yield. For example, similar orientational dependences were observed in the original flux of electrons produced as a result of transmission through thin single crystals.[11]

We can conclude from the given data that for a complete description of the process of γ radiation from crystals, a theory which takes into account a change in the electron flux in crystals of different thickness or different orientation, must be developed. The results obtained show that this change in flux occurs over a wider range of orientational angles than previously assumed and that the contribution of the radiation of above-the-barrier particles due to transitional channeling to the spontaneous γ radiation due to electron channeling is considerable (and in some cases dominant). The known coherent-radiation mechanism is apparently realized for crystal orientations in the region $\psi \gtrsim (5$–$10)\psi_c$, which corresponds to the critical channeling angles.

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