Observation of intensive γ-radiation of 900-MeV electrons in the case of channeling in a diamond

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Gamma-radiation spectra were recorded when 900-MeV electrons passed through single-crystal diamond and graphite targets of the same radiation thickness. We show that in the case of electron channeling the yield of 16-MeV γ-rays is ~50-fold higher for disoriented diamond or graphite.

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Recent theoretical works[1–5] discuss the characteristics of specific electro-magnetic radiation in the case of channeling of ultrarelativistic charge particles in crystals. The mechanism of this radiation was discussed earlier for low-energy electrons.[6,7] In comparison with the known synchrotron and undulatory radiation the photon spectrum in the case of channeling is shifted into the hard region and the spectral density is assumed to be two–three orders higher than for bremsstrahlung. Electromagnetic radiation with similar properties is of considerable interest, in particular for applications, and, therefore, experiments to discover and study it are essential. Indications that γ-radiation is possible in the course of electron channeling is, clearly, given by the anomalous increase in the flux of bremsstrahlung photon energy in crystals,[8] and also by preliminary results on the increase in the spectral density of the low-energy γ-ray yield.[9,10]

In this work we present the first experimental results of investigation of the spectral composition and orientation functions of γ-radiation yield for 900-MeV electrons which pass through a diamond single crystal in the axial channeling mode.

Measurements were carried out on the internal electron beam of the Tomsk synchrotron. The experimental setup is similar to an earlier scheme.[9] In the course of passing through a diamond single crystal 0.35-mm thick (0.0028 rad. unit length) placed in a goniometric device, electrons emit photons in a cone with an aperture $\Delta\theta \sim \gamma^{-1}$ (γ is the Lorentz factor). At the energy $E = 900$ MeV, $\gamma^{-1} = 0.55 \times 10^{-3}$ rad and, therefore, $\theta_c = 0.6 \times 10^{-3}$ rad for the photon beam collimator. The spectral composition of radiation $N_\gamma(\omega)$ was investigated by means of a double arm magnetic γ-spectrometer with energy resolution $\xi = 6–7\%$ in the energy interval $\omega = 8.5–40$ MeV, and for γ-rays $\omega = 200$ MeV, $\xi = 3\%$. The total energy of the photon beam was measured by gaussmeter with 3% error. The accelerator current was measured by an induction pickup (number of electrons N_e on a stable orbit directly before discharge onto a target for each accelerating cycle) with a relative current measurement error of 3%. The angular divergence of the internal electron beam according to data from a back-scattered laser beam,[11] did not exceed $(1–3) \times 10^{-4}$ rad which was less than the critical angle for axial channeling $\psi_c = 3 \times 10^{-4}$ rad.

Figure 1 shows the total yield Q/N_e and the yield of γ-rays with energy $\omega = 20$

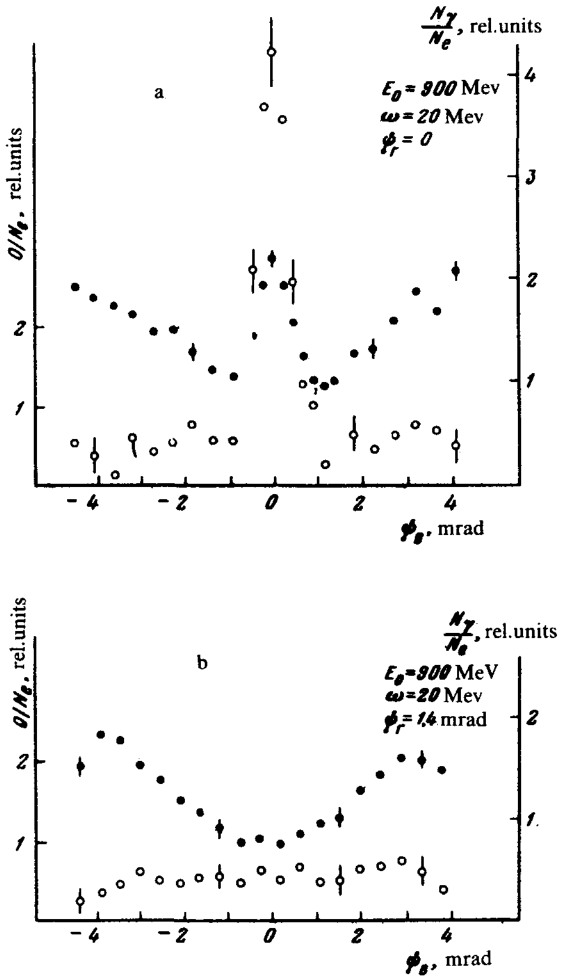

FIG. 1. Orientation functions of total radiation yield (dark circles) and yield of γ-rays with energy $\omega = 20$ MeV (light circles).

MeV as functions of angle ψ_B between the $(1\bar{1}0)$ plane of the diamond and electron momentum $\mathbf{p}_1$. Figure 1a corresponds to disorientation in the (001) plane $\psi_r = 0$ (ψ_r is an angle between the planes (001) and $(\mathbf{p}_1, \langle 1\bar{1}0\rangle)$. A maximum is observed when electrons travel along the $\langle 110\rangle$ axis for both the total energy Q/N_e and γ-ray yield N_γ/N_e $\omega = 20$ MeV, which contradicts predictions of the theory of coherent bremsstrahlung.[12] The total width of the maximum is the same for both functions $\Delta\psi = 1.1 \times 10^{-3}$ rad which is in agreement with a value $2\psi_c$ of the critical angle when the angular divergence of electron beam is taken into account. The yield maximum width Q/N_e is apparently independent of γ-beam collimation in the interval $\theta_c = (0.4\text{–}2.5) \times 10^{-3}$ rad. Figure 1b shows results obtained for the yield from the (001) plane ($\psi_r = 1.4 \times 10^{-3}$ rad $> \psi_c$); anomalies were observed in neither the total yield nor γ-ray yield with $\omega = 20$ MeV.

To study the spectral characteristics of radiation we measured γ-spectra normal-

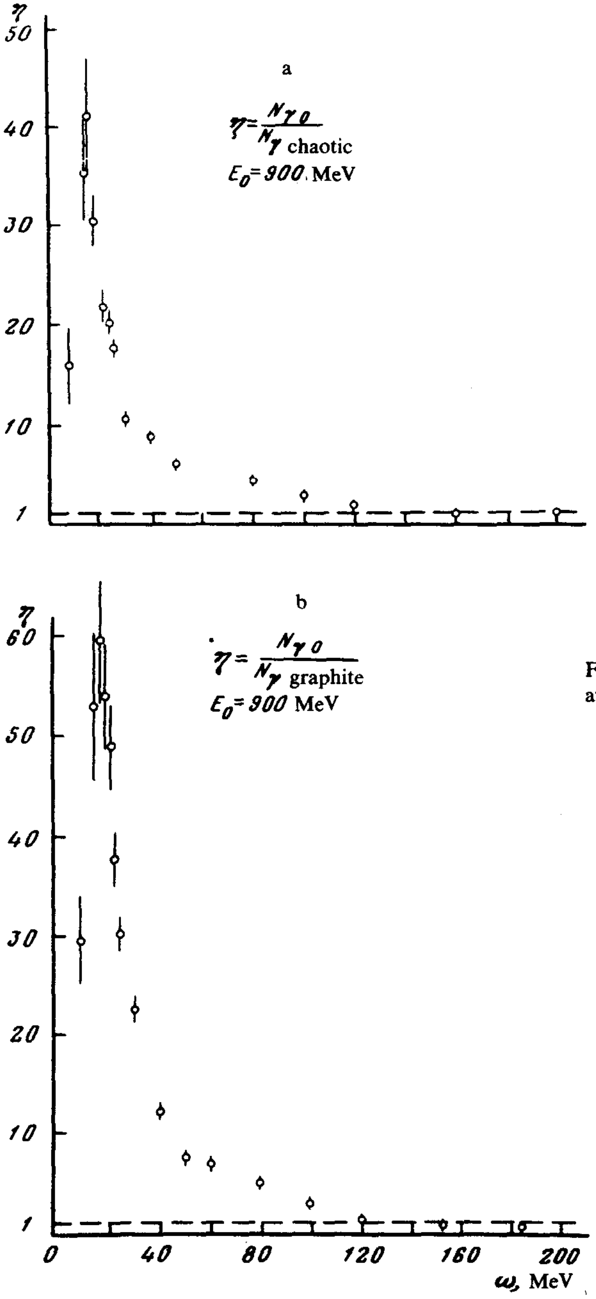

FIG. 2. Spectral characteristics of γ-radiation in the case of channeling.

ized to the number of electrons: 1) $N_\gamma(\omega)_0$–oriented diamond ($\psi_B = \psi_\Gamma = 0$–channeling along the $\langle 110 \rangle$ axis); 2) $N_\gamma(\omega)_x$–disoriented diamond ($\psi_B = 3°$, $\psi_\Gamma = 0.5°$); 3) $N_\gamma(\omega)_{\text{graph}}$–graphite target with a thickness equal to that of a diamond (in radiation lengths). Figure 2 shows yield ratios of γ-rays from oriented diamond to disoriented diamond $\eta_1 = N_\gamma(\omega)_0/N_\gamma(\omega)_x$ and to graphite $\eta_2 = N_\gamma(\omega)_0/N_\gamma(\omega)_{\text{graph}}$. When finding the ratio η we eliminated errors associated with the determination of effectiveness of the γ-spectrometer in the low-energy region. In the case of γ-rays with energy $\omega \simeq 16$ MeV we observed a maximum yield excess of $\eta_{1\,\max} \approx 43$ and $\eta_{2\,\max} \approx 60$, and in the case of γ-rays with energy $\omega \geqslant 120$ MeV the yields are practically identical for all three cases. For energies $\omega < 16$ MeV a statistically significant decrease is observed for the γ-ray yield ratio.

The observed anomalous yield of low-energy γ-rays may be explained in terms of emission of electrons in the course of channeling when they move connectedly with individual atomic chains in a crystal along spiral trajectories. In the field of the atomic chain $U(r) = -2^{1/2}Ze^2a_{TF}/rd$,[7] where a_{TF} is the screening radius, d is the interatomic distance, the trajectory oscillation frequency of a given particle is $\Omega_0 = (2/\epsilon_\perp)^{3/2}d\,(2^{1/2}Ze^2a_{TF}m^{1/2})^{-1}$, where m is electron relativistic mass and $\epsilon_\perp = U(r_i) + E\psi^2$is the total transverse energy with the r_i-coordinate point of particle injection into an atomic chain field. This results in a frequency of the first harmonic of radiation in the direction θ of the angle of observation

$$\omega_0 = \Omega_0(1 - v/c\cos\theta)^{-1} \approx 1.85\cdot 10^{13}|\epsilon_\perp|^{3/2}(1 - v/c\cos\theta)^{-1}\ [\sec^{-1}],$$

where ϵ may take on values for stable trajectories (10–50) eV which corresponds to an energy region of γ-rays $\omega = 15$–165 MeV for $\theta = 0$, that is in agreement with the experimental data. To calculate the spectral properties of radiation, for example within the framework of the method in Ref. 13, one must take into account the angles and point coordinates of electron beam injection into the field of an atomic chain. In the general case, the process of γ-ray emission from single crystals will determine not only the electrons of the current associated with the atomic chain but also particles with motion exceeding the barrier energy with $\epsilon_\perp > U(r_0)$ ($r_0$is one half the distance between atomic trains) from the region of "intermediate channeling" which is responsible for the coherent effects.[9]

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[1] V.G. Baryshevskiĭ and I.Ya. Dubovskaya, Doklady AN SSSR **231**, 1335 (1976) [Sov. Phys. Dokl. **21**, 741 (1976)]; Phys. Stat. Sol. (b) **82**, 403 (1977).

[2] M.A. Kumakhov, Doklady AN SSSR **230**, 1077 (1976) [Sov. Phys. Dokl. **21**, 581 (1976)].; Phys. Lett. **37A**, 17 (1976); Zh. Eksp. Teor. Fiz. **72**, 1489 (1977) [Sov. Phys. JETP **45**, 781 (1977)].

[3] M.I. Podgoretskiĭ, OIYaI; R2-10986, Dubna, 1977; R2-11140, Dubna, 1977.

[4] A.I. Akhiezer, V.F. Boldyshev and N.F. Shul'ga, Doklady AN SSSR **236**, 830 (1977) [Sov. Phys. Dokl. **22**, 569 (1977)].

[5] V.A. Bazylev and N.K. Zhevago, Zh. Eksp. Teor. Fiz. **73**, 1697 (1977) [Sov. Phys. JETP **46**, 891 (1977)].

[6] N.P. Kalashnikov, E.A. Koptelov and M.I. Ryazanov, Fiz. Tverd. Tela **14**, 1211 (1972) [Sov. Phys. Solid State **14**, 1033 (1972)].

[7] A.A. Vorob'ev, V.V. Kaplin and S.A. Vorob'ev, Nucl. Instrum. Meth. **127**, 265 (1975).

[8] V.L. Morokhovskiĭ, G.D. Kovalenko, I.A. Grishaev, A.N. Fisun, V.I. Kasilov, B.I. Shramenko and A.N. Krinitsyn, Pis'ma Zh. Eksp. Teor. Fiz. **16**, 162 (1972) [JETP Lett. **16**, 112 (1972)].

[9] S.A. Vorob'ev, B.N. Kalinin, V.V. Kaplin and A.P. Potylitsyn, Pis'ma Zh. Tekhn. Fiz. **4**, 1340 (1978) [Sov. Tech. Phys. Lett. **4**, 539 (1978)]; Izvest. Vyssh. Ucheb. Zaved., Ser. Fizika, No. 11, 117 (1978).

[10] A.O. Aganyants, N.Z. Akopov, Yu.A. Vartanov and G.A. Vartapetyan, Preprint EFI-312 (37)-78, Erevan, 1978.

[11] A.V. Peshkov, Dissertation, TPI, Tomsk, 1974.

[12] U. Timm, Fortsch. Phys. **17**, 765 (1969).

[13] V.N. Baĭer, V.M. Katkov and V.M. Strakhovenko, Zh. Eksp. Teor. Fiz. **63**, 2121 (1972) [Sov. Phys. JETP **36**, 1120 (1973)].