Radiation of ultrarelativistic electrons in a quartz single crystal

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The energy spectra of ultrarelativistic 4.5-GeV electrons and their dependence on the thickness of the crystal have been studied for the first time under conditions of axial and planar channeling in a piezoelectric quartz crystal.

The determination of the effect of spectral and angular characteristics of the emitted γ rays on the thickness of the crystal is important in the study of radiation of electrons under conditions of axial and planar channeling.[1,2]

In the first place, such studies make it possible to determine the contribution of various mechanisms for radiation of high-energy electrons as they pass through a crystal. This determination is made on the basis of the change in the spectral composition of the radiation with changing dynamical parameters of the electrons as they move deeper into the interior of the crystal. Secondly, they make it possible to determine the maximum thickness of the crystal at which the yield of the emitted γ rays is maximum. This information is of considerable importance for practical application of γ-ray beams generated by channeled electrons.

On the other hand, these studies are necessary in order to broaden the range of the radiators studied: crystals with various structures and physical properties, with the goal of intensifying the radiation from channeled particles.[3]

In the present letter we report for the first time the results of a study of the spectral characteristics of the radiation of electrons under conditions of axial and planar channeling in a piezoelectric crystal of α quartz. As the targets we used single crystals whose $\langle 100 \rangle$ axis or the $(0\bar{1}1)$ plane was oriented in the direction of motion of the electrons. The X-cut crystals had the following thicknesses: 1, 2.9, 3.5, and 6 mm.

The experiment was carried out in an electron beam of the Erevan synchrotron with an energy $E_0 = 4.5$ GeV and a beam divergence of 4.4×10^{-5} rad. The experimental setup is shown in Fig. 1. The electron beam is detected in the coordinate detector (proportional counter) and is aimed at the crystal target T which is situated inside a vacuum goniometric device. In the magnet the electrons are separated from the emitted γ rays and are detected in the scintillation counters C_{11}–C_{22}, while the γ rays are detected in the total-absorption spectrometer.

The proportional detector, with a 1-mm winding pitch of the wires, was used to measure the profile of the electron beam before the electrons struck the crystal target

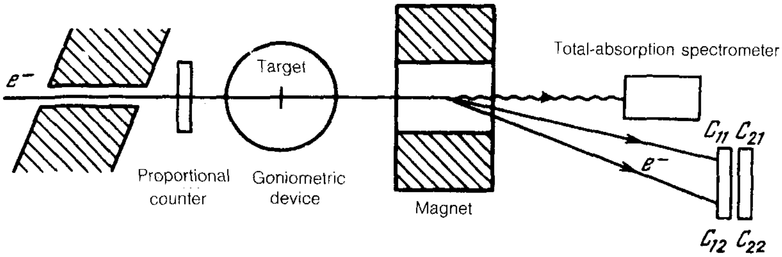

FIG. 1. Experimental setup.

and to cut off the events in which the primary electron did not strike the target during the measurements.

The goniometric device makes it possible to remotely rotate the target relative to the horizontal and vertical axes within an error of 4.4×10^{-5} rad and to replace the targets under the beam.

The scintillation counters C_1 and C_2 have the dimensions $100\times10\times2$ cm and each counter has two photomultipliers. The electrons are detected in the energy range 4.5–2.7 GeV, which corresponds to the energy range in which the γ rays are detected, 0–1.8 GeV.

The total-absorption spectrometer is based on an NaI crystal with dimensions $13\times13\times30$ cm and is equipped with one PM-82 photomultiplier. The spectrometer was calibrated beforehand using a secondary-electron beam in the energy range 50–3000 MeV.

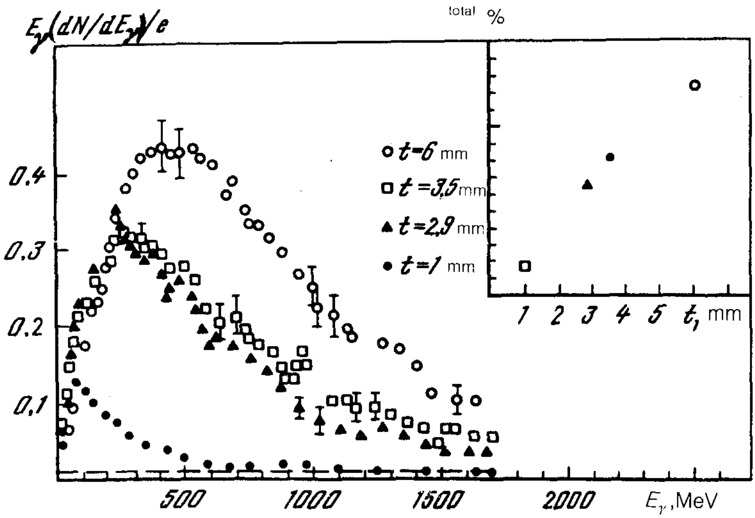

FIG. 2. Spectra of electron radiation under conditions of axial channeling in quartz crystals for thicknesses $t = 1.0$, 2.9, 3.5, and 6.0 mm.

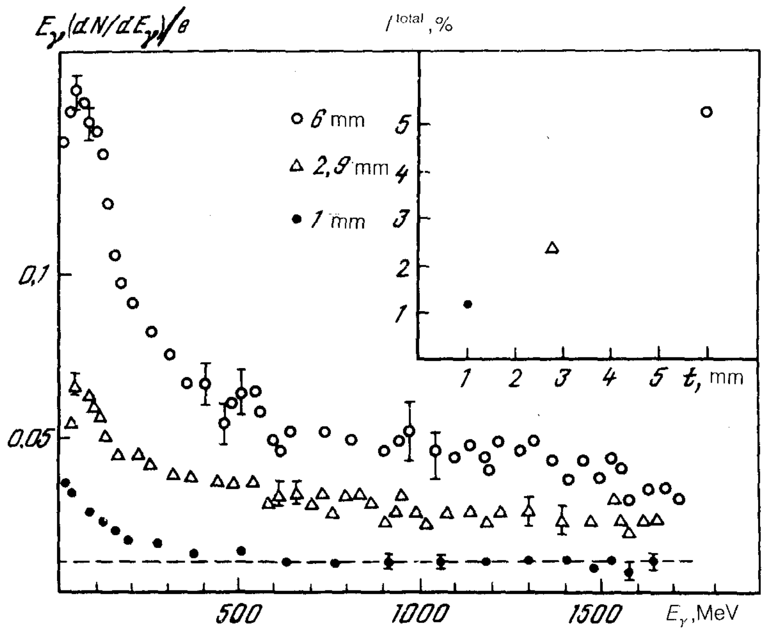

FIG. 3. Spectra of electron radiation under conditions of planar channeling in quartz crystals for thicknesses $t = 1.0$, 2.9, and 6.0 mm.

Figure 2 shows the spectral dependence of the electron radiation under conditions of axial channeling along the ⟨100⟩ crystallographic axis for $t = 1$, 2.9, 3.5, and 6 mm. Also shown in this figure is a plot of the total energy lost by the electron due to the radiation, I^{total}, with respect to the initial energy, as a function of the thickness of the crystal.

Figure 3 shows the spectra of electron radiation under the conditions of planar channeling in the $(0\bar{1}1)$ crystallographic plane for $t = 1$, 2.9, and 6 mm, and also the plot of I^{total} versus the thickness of the crystal.

The dashed line in both figures represents the radiation levels of a disoriented crystal for $t = 1$ mm (in Fig. 2, for clarity, the radiation intensity has been increased by a factor of two in the case of a disoriented crystal).

The results obtained by us shows that all the measured spectra have a peak structure. The exception is the case of planar channeling for a crystal of thickness $t = 1.0$ mm, where the peak energy of the emitted γ rays is below (presumably because of the low potential barrier) the detection threshold of the total-absorption spectrometer.

In the case of axial channeling, the spectra are displaced toward harder γ radiation in comparison with the corresponding spectra for planar channeling. With an increase in the thickness of the radiators, all the spectra, especially those for the planar channeling, become broader and are displaced up the frequency scale. This behavior can apparently be explained by (a) radiation multiplicity: the spectrometer sums the

TABLE I.

Thickness (mm)	Axis						Plane			
t	I^{total}, %	E_γ^{peak}, MeV	ΔE_γ, MeV	$I^{\text{peak}}/I^{\text{disorient}}$	N_γ	I^{total}, %	E_γ^{peak}, MeV	ΔE_γ, MeV	$I^{\text{peak}}/I^{\text{disorient}}$	N_γ
1,0	1,83	56	173	20	0.42	1,11	25	160	3,7	0.16
2,9	6,62	240	600	18	0.86	2,41	56	440	2,3	0.43
3,5	8.04	240	713	14	0.84	–	–	–	–	–
6.0	12,30	500	854	11	0.89	5.14	56	280	2,8	0.61

energy of several γ rays which have been emitted simultaneously, recording them as a single γ ray with a total energy (the probability for the occurrence of this effect increases with increasing thickness of the crystal) and (b) as the thickness of the radiators is increased, the contributions from the above-the-barrier, quasi-channeled, and coherent bremsstrahlung and also the contribution from the inverse transition of quasi-channeled particles to the channeling regime increase because of the electron scattering.

Table I gives the main characteristics of the radiation spectra, where $I^{\text{total}} = \Delta E / E_0$ is the ratio of the total energy lost by the electrons due to the radiation to the initial energy, E_γ^{peak} is the peak energy of the emitted γ rays, ΔE_γ is the half-width of the spectral curve, $I^{\text{peak}}/I^{\text{disorient}}$ is the ratio of the radiation intensity of the peak-energy γ rays to the radiation intensity of the disoriented target, and $N_\gamma = N_e^{\text{emitted}}/N_e^{\text{incident}}$ is the ratio of the number of emitted electrons to the number of electrons incident on the target.

In determining N_γ we took into account the corrections for the γ-ray absorption in the target and for the dependence of the efficiency of the apparatus on the γ-ray energy.

We see in Table I (especially in the case of axial channeling) that the number of γ rays emitted per electron reaches the saturation point even if the thickness of the plate is 2.9 mm. We also see that as the thickness of the plate increases from 1 mm to 6 mm, the ratio of the peak radiation intensity to the corresponding value for the disoriented crystal decreases by approximately one-half. This suggests that in the case of thick crystals the main radiation mechanism (particle channeling) is augmented by other mechanisms, which give rise to the broadening of the spectrum. The results of our study show that quartz single crystals can be used as efficient radiators to produce intense γ-ray beams generated by high-energy electrons under conditions of axial and planar channeling.

[1] R. O. Avakyan *et al.*, Pis'ma Zh. Tekh. Fiz. **11**, 1391 (1985) [Sov. Tech. Phys. Lett. **11**, 574 (1985)].
[2] R. O. Avakyan *et al.*, Rad. Effects **91**, 257 (1986).
[3] A. R. Mkrtchyan, R. A. Gasparyan, and R. G. Gabrielyan, Zh. Eksp. Teor. Fiz. **93**, 432 (1987) [Sov. Phys. JETP **66**, 248 (1987)].

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