Bremsstrahlung spectra of 1.2-GeV electrons in a silicon single crystal at an angle $\theta = 1.7 \times 10^{-2}$ radian

G. L. Bochek, I. A. Grishaev, G. D. Kovalenko, and V. I. Kulibaba
Khar'kov Physicotechnical Institute, Ukrainian Academy of Sciences

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The radiation spectra of electrons in amorphous aluminum targets and silicon single crystals with [110] and [111] orientations were measured at an angle $\theta = 1.7 \times 10^{-2}$ rad with respect to the electron beam. It is shown that when the axial-channeling conditions are satisfied, the intensity of the electron radiation increases by a factor of 1.5 and 1.4, respectively, as compared with the disoriented crystals.

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The interaction of electrons with single crystals has several unique features. One of these features is the spatial redistribution of particles as they move through the crystal when the axial-channeling conditions are satisfied; this can result in an increased electron radiation intensity.[1] As shown elsewhere,[2–6] the electron radiation intensity increases when the axial channeling conditions are satisfied. It must be noted that enhanced radiation intensity at photon energies $E < 0.1E_0$, where E_0 is the initial electron energy, is also caused by coherence effects[5] and by spontaneous emission.[7] Moreover, as the electrons move along the crystal axis, the mean-square, multiple-scattering angle increases, in contrast to a disoriented crystal.[2] Therefore, the increase in the radiation intensity, which is caused by spatial redistribution of the electron beam, must depend on the radiation collimation angle. It follows from experimental results that in one case[3] no noticeable radiation increase is observed at photon energies $E > 0.1E_0$, as compared with a disoriented crystal, when the axial-channeling conditions are satisfied for the collimated electron radiation, whereas in the other case[8] the radiation decreases at photon energies $E \sim E_0$. In contrast to a disoriented crystal, the electron radiation intensity increases in the case of uncollimated radiation at photon energies $E > 0.1E_0$.[2]

Thus, to determine the influence of the spatial redistribution of the electron beam on the radiation intensity, we must either take into account the influence of processes or establish conditions for which their contribution is small.

The method proposed in this paper is based on the fact that the contribution of coherence effects, spontaneous emission, and multiple scattering for a given photon energy decreases with increasing radiation angle, and only spatial redistribution of the particle beam in the crystal influences the radiation at photon energies $0.01E_0 < E < E_0$ at an angle $\theta \gg mc^2/E_0$, where m is the electron mass and c is the velocity of light.

Our purpose was to investigate the influence of spatial redistribution of the electron beam on the spectral characteristics of their radiation in a silicon crystal.

This work was performed using the LU 2-GeV linear accelerator at the Khar'kov

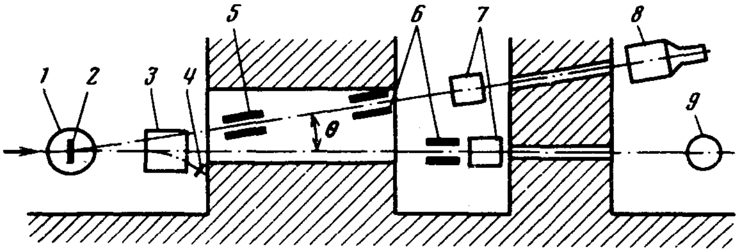

Fig. 1. Experimental setup. 1, Goniometer; 2, crystal; 3 and 7, magnets; 4 and 9, ionization chambers; 5 and 6, collimators; 8, total-absorption spectrometer.

Physicotechnical Institute of the Ukrainian Academy of Sciences. The measurements were made using the method suggested earlier.[9] The experimental setup is shown in Fig. 1. The electrons with an energy $E_0 = 1.2$ GeV, a divergence of 2×10^{-4} rad, and an energy spread $\Delta E / E_0 = 1\%$, which were placed in a goniometric system, were focused on silicon single crystals with [110] and [111] orientations and thickness of 240 and 300 μm, respectively. The electrons were magnetically deflected behind the target and recorded by an ionization chamber. A photon beam at an angle $\theta = 1.7 \times 10^{-2}$ rad was shaped by collimators, purified magnetically and recorded by a total-absorption CsI(Tl) spectrometer.[5] The solid angle for photon recording was $\Delta\Omega = 2.7 \times 10^{-7}$ sr. The electron intensity was selected in such a way that the frequency of photon recording by the spectrometer did not exceed 13 Hz (the current-pulse frequency of the accelerator was 50 Hz). Orientation of the silicon single crystals (i.e., alignment of the [110] and [111] axes with the particle-beam direction) was accomplished by means of an ionization chamber, which was placed in line with the photon beam, using a method suggested in Ref. 10.

Since both radiation intensity and particle scattering depend on the orientation angle of the single crystals with respect to the particle direction,[2] we had to experimentally verify the effect of the mean-square, multiple-scattering angle on the electron radiation intensity at an angle $\theta = 1.7 \times 10^{-2}$ rad. To do this, we used two amorphous aluminum targets with thicknesses of 200 μm and 500 μm, instead of silicon single crystals. The 200-μm target is equivalent in scattering to the 240-μm-thick, disoriented, silicon single crystal, and the 500-μm-thick aluminum target is equivalent to the oriented crystal.[2] The electron bremsstrahlung spectra for the aluminum targets are shown in Fig. 2. The number N of photons in a 1-MeV energy interval at a solid angle $\Delta\Omega$, which is multiplied by the photon energy E, is plotted along the vertical axis. The photon energy is plotted along the horizonal axis. The solid curves represent the calculated electron bremsstrahlung spectra in the Born approximation with allowance for the energy resolution of the spectrometer, as well as the pulse counting errors and superpositions in the spectrometer. The unshielded Coulomb potential used in the calculations is valid for momentum transfer $q \sim me$ which is realized in this experiment: $q \gg q_{\min}$, $q_{\min} = \theta^2 E_0 x$: $2c(1-x)$, and $x = E_\sim / E_0$ (in this experiment $E > 0.05 E_0$).

The angle θ used in the radiation intensity calculations, which was selected on the basis of the best fit of the calculated and experimental results, was equal to 1.7×10^{-2}

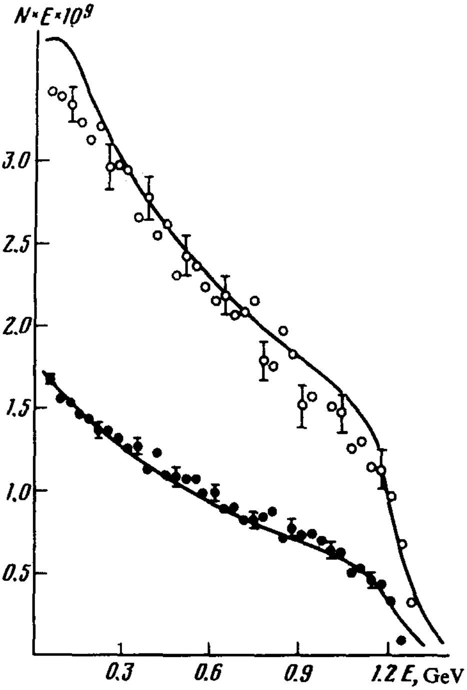

Fig. 2. Bremsstrahlung spectra of electrons from amorphous aluminum targets placed at an angle $\theta = 1.7\times10^{-2}$ rad. ●, 200-μm-thick aluminium; ○, 500-μm-thick aluminum; ——, calcualtion in the Born approximation.

rad, in good agreement with the previously measured angle $\theta = (1.7 \pm 0.1)\times10^{-2}$ rad. It follows from the agreement of the experimental and calculated results that the intensity of electron radiation at an angle $\theta = 1.7\times10^{-2}$ rad for the investigated thicknesses, as expected from theoretical estimates, does not depend on the mean-square, multiple-scattering angle.

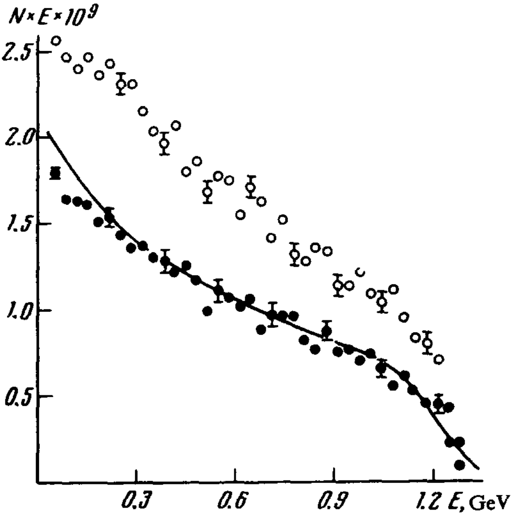

Fig. 3. Bremsstrahlung spectra of electrons from a 240-μm-thick silicon single crystal. ●, disoriented single crystal; ○, oriented single crystal with the [110] axis parallel to the electron beam; ——, calculation in the Born approximation.

The electron bremsstrahlung spectra of the silicon single crystal with [110] orientation are shown in Fig. 3 for the oriented (axial-channeling condition is satisfied) and disoriented crystal. For the disoriented crystal the experimental results are in good agreement with the calculation made in the Born approximation for an amorphous silicon target with allowance for the energy resolution of the spectrometer, the pulse-counting errors and the superpositions in the spectrometer. For the oriented crystal the bremsstrahlung intensity is increases by a factor of 1.5; the shape of the spectrum is unchanged, which indicates an absence of coherent and spontaneous radiation in the measured energy interval. A 1.4-fold increase of the radiation intensity as compared with the disoriented crystal can also be observed for the 300-μm-thick silicon crystal oriented with the [111] axis parallel to the beam.

Thus, by using the described method we have determined the effect of spatial redistribution of the electron flux on the intensity of the normal bremsstrahlung when the axial-channeling conditions are satisfied. Since the momentum transfer $q \gg q_{\min}$ is realized in this measurement geometry, the spatial redistribution of the electron flux occurs in such a way that its density increases by a factor of 1.5 in the region $R \ll \hbar/q_{\min}$ ($\hbar$ is Planck's constant) for the [110] crystal axis and by a factor of 1.4 for the [111] axis.

In conclusion, the authors thank the staff of the LU 2-GeV accelerator for providing precise electron-beam parameters.

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