Coherent type-*B* bremsstrahlung as a possible source of monochromatic γ rays

A. P. Potylitsyn

Scientific-Research Institute of Nuclear Physics, S. M. Kirov Tomsk Polytechnical Institute, 634061, Tomsk

(Submitted 12 November 1990)
Pis'ma Zh. Eksp. Teor. Fiz. **53**, No. 1, 12–14 (10 January 1991)

A new method is proposed for generating monochromatic γ rays. The method is based on a coherent bremsstrahlung of electrons moving along crystallographic axes. If the beam is highly collimated, the energy spread of the γ rays can be kept below 1%, and the peak-to-pedestal ratio can be raised above 10.

Coherent bremsstrahlung is widely used by experimentalists to generate polarized photon beams (Ref. 1 and the bibliography there). Another characteristic of a coherent bremsstrahlung beam—the quasimonochromatic nature of the spectrum—has found essentially no use experimentally, because the monochromaticity is low and there is a large contribution from the continuum (Refs. 2 and 3, for example). A beam with a monochromaticity $\Delta\omega/\omega = 13\%$ was produced by Tsuru *et al.*[4] through very careful collimation of a coherent bremsstrahlung beam generated by electrons with an energy $E_0 = 1$ GeV.

The silicon target used there was in the orientation corresponding to the "row effect." There appears to be no way to improve the monochromaticity of the coherent bremsstrahlung beam by that approach.

For electrons moving along a crystallographic axis, the radiation accompanying channeling (this radiation is a consequence of the continuous potential of a row) is accompanied by a mechanism of coherent bremsstrahlung (as a result of specifically the discrete positioning of the atoms along the row), which Überall called "type-*B* coherent bremsstrahlung."[5] If the periodicity of the positions of the atoms along the axis is a, the energy of the coherent maxima, ω_n, is found from the condition

$$\frac{1}{2E_0}\frac{\omega_n}{E_0-\omega_n} = \frac{2\pi}{a}n, \qquad n = 1, 2, \ldots, \tag{1}$$

which corresponds to the situation in which an entire plane of reciprocal-lattice sites falls in the Überall disk. By analogy with the existing terminology (the row and point effects), this orientation might be called the "plane effect."

In Eq. (1) and below, a system of units with $\hbar = m = c = 1$ is being used.

From (1) we find an expression for the energy of the coherent maxima:

$$x_n = \frac{\omega_n}{E_0} = \frac{\frac{4\pi E_0}{a}n}{1+\frac{4\pi E_0}{a}n}. \tag{2}$$

It follows from (2) that for an energy $E_0 \sim 1$ GeV the first maximum corresponds to a

© 1991 American Institute of Physics

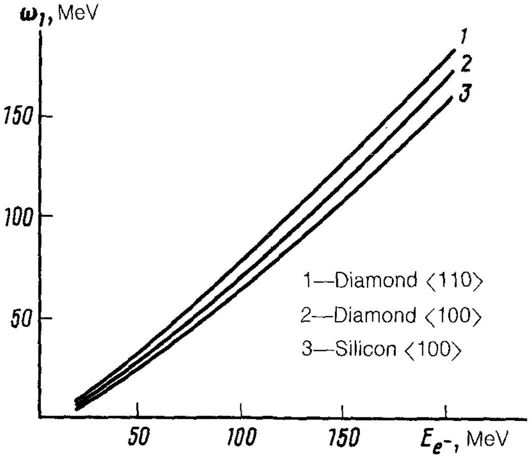

FIG. 1. Energy of the first coherent peak in the radiation spectrum as a function of the electron energy for various crystals and various orientations.

photon energy $x \approx 0.95$, i.e., lies at energies near the end of the spectrum, where coherent effects are extremely weak.

For electrons with an energy $E_0 \sim 10^2$ MeV, in contrast, the situation is radically different. Figure 1 shows the position of the first coherent maximum in the spectrum as a function of the electron energy for diamond and silicon single crystals.

The monochromaticity of the peak, $\Delta\omega/\omega$, is determined by the collimation angle θ_c from expression (1), which determines the upper boundary of the peak, and from the corresponding expression for the lower boundary:

$$\frac{1}{2E_0}\frac{\omega_{min}}{E_0-\omega_{min}}(1+E_0^2\theta_c^2)=\frac{2\pi}{a}n. \tag{3}$$

From (1) and (3) we easily find the expression

$$\frac{\Delta\omega}{\omega_n}=\frac{\Delta x}{x_n}=(1-x_n)E_0^2\theta_c^2. \tag{4}$$

For collimation angles $\theta_c \ll \gamma^{-1}$ the monochromaticity can reach values $\lesssim 10^{-2}$.

The intensity spectrum was calculated from the well-known formulas from the theory of coherent bremsstrahlung. One argument in favor of this approach is that the maxima of type-B coherent bremsstrahlung lie in the hard part of the spectrum, while the violation of the standard theory of coherent bremsstrahlung occurs in the soft part of the spectrum, as was shown experimentally in Ref. 6.

A calculation was carried out for a diamond target in the ⟨100⟩ orientation. The electron energy was $E_0 = 150$ MeV, and the collimation angle was $\theta_c = 0.6$ mrad.

The incoherent contribution was calculated by ignoring the bremsstrahlung involving electrons.

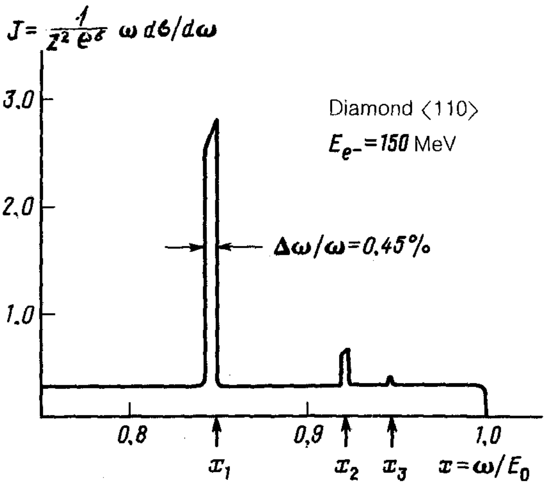

FIG. 2. Intensity spectrum of type-*B* coherent bremsstrahlung for a collimation angle $\theta_c = 0.6$ mrad. The arrows show the positions of the coherent peaks for $n = 1, 2$, and 3.

Figure 2 shows the resulting radiation spectrum. The monochromaticity of the first peak is $\Delta\omega/\omega = 0.5\%$, in agreement with the value predicted by expression (4). The intensity at the maximum exceeds that of the continuum pedestal, η, by a factor ~ 10. As the collimation angle is reduced, there are improvements in both the monochromaticity (as a result of the contraction of the Überall disk) and the factor by which η is exceeded (at a fixed J_{coh}, J_{incoh} is suppressed as $E_0^2\theta_c^2/1 + E_0^2\theta_c^2$).

For comparison with the known methods for generating monochromatic photons (in-flight positron annihilation and the scattering of laser photons by ultrarelativistic electrons), let us estimate the photon yield per electron in the first peak (Fig. 2).

For a diamond target 35 μm thick, the yield of monochromatic photons with an energy $\omega_1 = 127$ MeV would be $\sim 10^{-5}$ photon/e^-; the corresponding intensity of the photon beam is $\sim 10^7$ photon/s (for 10^{12} e^-/s, a typical intensity of an electron beam). This value is an order of magnitude above the intensity of a beam of annihilation photons[7] and two orders of magnitude above that of a beam of backscattered laser photons.[8] Furthermore, producing a photon beam with an energy $\omega \sim 100$ MeV would require that the laser photons be scattered by the electron beam of a storage ring with an energy $E_0 \sim 1$ GeV, while an electron accelerator with an energy $E_0 \gtrsim 100$ MeV would be quite adequate for the method which we are discussing here.

The characteristics of this new method for producing monochromatic photons appear to be quite competitive with those of the conventional methods, while this new method would be vastly simpler to realize.

[1] A. P. Potylitsyn, *High-Energy Polarized Photon Beams*, Energoatomizdat, Moscow, 1987.
[2] W. Kaune, O. Miller, W. Oliver *et al.*, Phys. Rev. D **11**, 478 (1975).
[3] R. O. Avakyan, A. É. Avetisyan, N. Z. Akopov *et al.*, Yad. Fiz. **33**, 362 (1981) [Sov. J. Nucl. Phys. **33**, 192 (1981)].

[4] J. Tsuru, S. Korokawa, J. Nishikawa *et al.*, Phys. Rev. Lett. **27**, 609 (1971).
[5] A. W. Saenz and H. Überall, Phys. Rev. B **25**, 4418 (1982).
[6] S. A. Vorob'ev, A. N. Didenkjo, V. N. Zabaev *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **32**, 261 (1980) [JETP Lett. **32**, 241 (1980)].
[7] G. P. Capitani, B. De Sanctis, C. Quaraldo *et al.*, Nucl. Instrum. Methods **216**, 307 (1983).
[8] A. L. Kazakov, G. Ya. Kezerashvili, L. E. Lazareva *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **40**, 445 (1984) [JETP Lett. **40**, 1271 (1984)].

Translated by D. Parsons