PARAMETRIC X-RAY RADIATION OF A RELATIVISTIC ELECTRON UNDER CONDITIONS OF ASYMMETRIC REFLECTION

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Coherent x-ray radiation of a relativistic electron crossing a single-crystal plate in the Laue scattering geometry is considered in a two-wave approximation of the dynamic diffraction theory [1]. Analytical expressions describing the spectral-angular distribution of parametric x-ray radiation (PXR) and diffraction transition radiation (DTR) formed on the atomic planes located at an angle $\delta$ to the crystal plate surface (asymmetric scattering) are derived. Dependence of the spectral-angular density of PXR, DTR, and their interference term on the angle $\delta$ is investigated.

INTRODUCTION

When a fast charged particle crosses a single crystal, its Coulomb field is scattered on the system of parallel atomic planes of the crystal, generating parametric radiation [2–4]. Currently, there are two approaches to describing PXR: kinematic [5, 6] and dynamic [7–9]. The kinematic approach takes into account interaction of every atom with the primary or refracted wave in the crystal. Unlike the dynamic approach, it neglects the atom interaction with that wave field that is generated in the crystal by the cumulative scattering on all other atoms, in other words, it does not include multi-wave scattering, in particular, interaction of a wavelet with the refracted wave. The dynamic approach was developed in [10, 11]. Recently, the dynamic effects in the parametric x-ray radiation have been addressed in [12–14]. The cited works made use of a symmetric reflection scheme. Under the conditions of symmetric reflection in the Bragg geometry the surface of a crystal target is located parallel to, and the Laue geometry – perpendicular to the system of diffracting atomic planes.

The case of symmetric reflection of parametric x-ray radiation in the Bragg geometry was reported in [15], and transition radiation (TR) and diffraction transition radiation (DTR) were discussed in [16, 17]. In this work we address coherent x-ray radiation of a relativistic electron crossing a single-crystal plate in the Laue scattering geometry. We derive the expressions for spectral-angular distribution of parametric x-ray radiation, diffraction transition radiation, and the term describing their interference in the general case of asymmetric reflection, that is, including different orientation of atomic planes of the crystal with respect to its surface (angle $\delta$). We show that for a fixed angle of incidence ($\theta_0$) of a relativistic electron on a system of parallel atomic planes of the crystal, a decrease in the angle $\delta$ results in spectral broadening of the parametric x-ray radiation and, as a result, to an increase in the frequency-integral radiation yield. Also, the work investigates the effect of reflection symmetry on the DTR angular density and the effect of PXR and DTR on the total angular density.

SPECTRAL-ANGULAR DISTRIBUTION OF RADIATION

Let us consider radiation of a fast particle crossing a single-crystal plate at a constant velocity $V$ (Fig. 1). To solve this problem we shall use an equation for the Fourier image of the electromagnetic field given by

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\[ E(k, \omega) = \int dt \, d^3 r \, E(r, t) \exp(i \omega t - ikr). \tag{1} \]

Since the field of the relativistic particle can, to a high-accuracy, be taken to be transverse, then the incident \(E_0(k, \omega)\) and diffracted \(E_g(k, \omega)\) electromagnetic waves would be determined by two amplitudes with different values of transverse polarization

\[
E_0(k, \omega) = E_0^{(1)}(k, \omega)e_0^{(1)} + E_0^{(2)}(k, \omega)e_0^{(2)},
\]
\[
E_g(k, \omega) = E_g^{(1)}(k, \omega)e_1^{(1)} + E_g^{(2)}(k, \omega)e_1^{(2)}. \tag{2}
\]

The unit polarization vectors \(e_0^{(1)}, e_0^{(2)}, e_1^{(1)}\) and \(e_1^{(2)}\) are selected as follows. Vectors \(e_0^{(1)}\) and \(e_0^{(2)}\) are perpendicular to vector \(k\), and vectors \(e_1^{(1)}\) and \(e_1^{(2)}\) are perpendicular to vector \(k_g = k + g\). Note that vectors \(e_0^{(2)}\) and \(e_1^{(2)}\) lie in the plane of vectors \(k\) and \(k_g\) (\(\pi\)-polarization), and vectors \(e_0^{(1)}\) and \(e_1^{(1)}\) are perpendicular to it (\(\sigma\)-polarization); \(g\) is the reciprocal lattice vector determining the system of atomic planes of the crystal. The system of equations for a Fourier image of an electromagnetic field in a two-wave approximation of the dynamic diffraction theory has the following form [18]:

\[
\begin{align*}
\left( \omega^2 (1 + \chi_0) - k^2 \right)E_0(x) + \omega^2 \chi_{-g} C(x) E_g(x) &= 8\pi^2 i e \omega \theta V P(x) \delta(\omega - kV), \\
\omega^2 \chi_g C(x) E_0^{(s)}(x) + \left( \omega^2 (1 + \chi_0) - k^2 \right)E_g^{(s)}(x) &= 0,
\end{align*}
\tag{3}
\]

where \(\chi_g, \chi_{-g}\) are the coefficients of the Fourier expansion of the dielectric susceptibility of the crystal with respect to the reciprocal lattice vectors \(g\)

\[
\chi(\omega, r) = \sum_g \chi_g(\omega) e^{igr} = \sum_g (\chi'_{g}(\omega) + i \chi''_{g}(\omega)) e^{igr}. \tag{4}
\]