Dynamic theory of coherent X-radiation of relativistic electron within a periodic layered medium in Bragg scattering geometry

S. Blazhevich [a,*], A. Noskov [b]

[a] Belgorod State University, Belgorod, Russia
[b] Belgorod University of Consumer's Cooperation, Belgorod, Russia

ABSTRACT

The theory of the coherent X-radiation of a relativistic electron crossing a periodic multilayer artificial structure is constructed in the Bragg scattering geometry for the general case of the asymmetric reflection of the particle coulomb field. The expressions describing spectral-angular characteristics of the radiation are derived and investigated in the paper. It is shown that the dynamic effects of the reflection asymmetry are manifested in the radiation in such a target as well as for the single crystal one.

1. Introduction

Up to the last time the relativistic particle radiation in a periodic lamellar structure was considered in Bragg scattering geometry only for the case, when the reflecting layers are situated parallel to the entrance surface of the target, which is the symmetric case. Also the radiation was considered as resonance transition radiation [1,2]. Then in [3] the parametric radiation was considered together with the resonance transition radiation.

Some progress has been made in the description of the radiation in such a media in the work [4,5], where the radiation in a multilayer periodic medium is represented in dynamic approximation as the coulomb field pseudo photon scattering on the amorphous layers by analogy with the coherent radiation process resulting by a relativistic electron in single crystal medium [6–9]. It's necessary to note that the radiation from the periodic layered structure in [1–5] was considered only in the special case of symmetric reflection. At that the paper [5] describes well the experimental results [10].

Subsequently, in [11–13] the dynamic theory was built by the authors of the present paper for the coherent radiation generated by the relativistic electron crossing a periodic layered medium in Laue geometry in general case of the reflection asymmetric relative to the target surface. It was revealed in these works that the radiation yield in artificial periodic structure materially exceeds the yield of the radiation in a crystal under similar conditions and the additional possibilities for the radiation yield increase as a result of the dynamic effects are available.

In the present work the dynamic theory of the relativistic electron coherent radiation in a periodic layered medium is developed in Bragg scattering geometry for general case of asymmetric reflection, when the reflecting layers are situated in the target at an angle related to the target surface (the symmetric reflection is a special case). The analytical expressions for the coherent radiation spectral-angular density generated by a relativistic electron in the multilayer periodic structure where the alternating layers of substance have sharply different dielectric susceptibilities are derived in the framework of two-wave approximation of dynamic diffraction theory in general case of asymmetrical field reflection. The dynamic theory of the relativistic electron coherent radiation in a periodic layered medium developed in this paper is in full agreement with the theory presented in [4,5] in the extreme case of symmetric reflection.

2. Radiation spectral-angular density

Let us consider the radiation of a relativistic electron crossing with steady speed $\mathbf{V}$ (see in Fig. 1) a multilayer periodic target consisting of periodically situated amorphous layers of thicknesses a and b ($T = a + b$ is the structure period) having the dielectric susceptibility χ_a and χ_b, respectively. In Fig. 1 following table of symbols are used: $\boldsymbol{\mu} = \mathbf{k} - \omega\mathbf{V}/V^2$ is the component of the virtual photon momentum perpendicular to the particle velocity vector $\mathbf{V}$ ($\mu = \omega\theta/V$, where $\theta \ll 1$ – the angle between vectors $\mathbf{k}$ и $\mathbf{V}$), θ_B

– Bragg angle, φ – azimuthal radiation angle, counted from the plane formed by velocity vector **V** and vector **g**, perpendicular to reflecting layers, θ'- radiation angle, (let's note, that $\theta' \approx \theta$). The magnitude of the vector **g** can be expressed by Bragg angle θ_B and Bragg frequency ω_B: $g = 2\omega_B \sin\theta_B/V$.

In the works [11–13] the dynamic theory of the coherent X-radiation generated by relativistic electron crossing the periodic layered structure was constructed for the case of asymmetric reflection in Laue geometry. In the condition of asymmetric reflection the radiation of relativistic electron in a single crystal target was considered by us also for Bragg scattering geometry (see [15]). Using procedures analogues to the ones presented in the work [14] (for crystal target) we have obtained in the present work the expression for the radiation field amplitude $E_{\rm Rad}^{(s)}$ in the direction of the radiated photon momentum $\mathbf{k_g}$ (see Fig. 1) as a sum of the contributions of two mechanisms, parametric X-radiation (PXR) and diffracted transition radiation (DTR): $E_{\rm Rad}^{(s)} = E_{PXR}^{(s)} + E_{DTR}^{(s)}$.

By substitution $E_{\rm Rad}^{(s)}$ into known expression for spectral-angular density of X-radiation

$$\omega\frac{d^2N}{d\omega d\Omega} = \omega^2(2\pi)^{-6}\sum_{s=1}^{2}\left|E_{\rm Rad}^{(s)}\right|^2 \qquad (1)$$

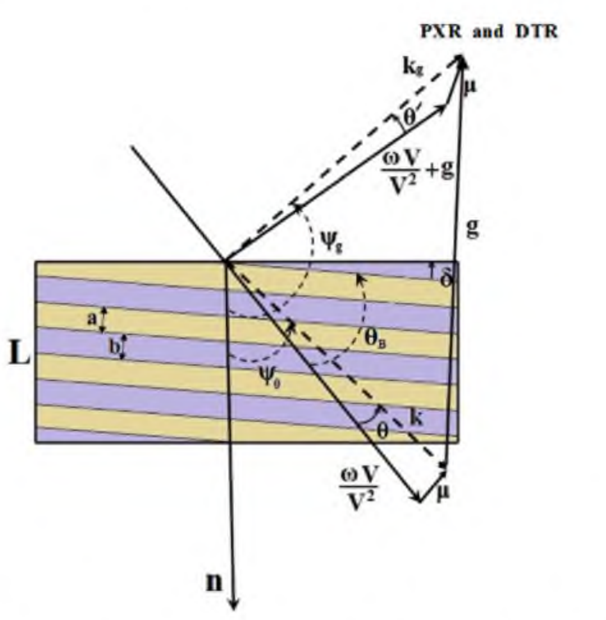

Fig. 1. Geometry of the radiation and the notation: θ and θ' are the angles of radiations, θ_B is the Bragg (the angle between the vector of the electron velocity **V** and the reflected layers), δ is the angle between the target surface and the layers of the target materials, **k** и $\mathbf{k_g}$ are the wave vectors of incident and diffracted photons.

we will obtain the expressions for spectral-angular density of PXR, DTR and the addition describing the interference of these radiation mechanisms:

$$\omega\frac{d^2N_{PXR}^{(s)}}{d\omega d\Omega} = \frac{e^2}{\pi^2}\frac{P^{(s)^2}\theta^2}{\left(\theta^2+\gamma^{-2}-\chi_0'\right)^2}R_{PXR}^{(s)}, \qquad (2a)$$

$$R_{PXR}^{(s)} = \left|\frac{\Omega_+^{(s)}}{\Delta^{(s)}}\frac{1-\exp(-ib^{(s)}\Delta_+^{(s)})}{\Delta_+^{(s)}} - \frac{\Omega_-^{(s)}}{\Delta^{(s)}}\frac{1-\exp(-ib^{(s)}\Delta_-^{(s)})}{\Delta_-^{(s)}}\right|^2 \qquad (2b)$$

$$\omega\frac{d^2N_{\rm DTR}^{(s)}}{d\omega d\Omega} = \frac{e^2}{\pi^2}P^{(s)^2}\theta^2\left(\frac{1}{\theta^2+\gamma^{-2}-\chi_0'} - \frac{1}{\theta^2+\gamma^{-2}}\right)^2 R_{\rm DTR}^{(s)}, \qquad (3a)$$

$$R_{\rm DTR}^{(s)} = \varepsilon^2\left|\frac{\exp\left(-ib^{(s)}(K^{(s)}/\varepsilon)\right) - \exp\left(ib^{(s)}(K^{(s)}/\varepsilon)\right)}{(\xi^{(s)}-K^{(s)}-i\rho^{(s)}(1+\varepsilon)/2)\exp(-ib^{(s)}(K^{(s)}/\varepsilon)) - (\xi^{(s)}+K^{(s)}-i\rho^{(s)}(1+\varepsilon)/2)\exp(ib^{(s)}(K^{(s)}/\varepsilon))}\right|^2, \qquad (3b)$$

$$\omega\frac{d^2N_{INT}^{(s)}}{d\omega d\Omega} = \frac{e^2}{\pi^2}P^{(s)^2} \times \frac{\theta^2}{\theta^2+\gamma^{-2}-\chi_0'}\left(\frac{1}{\theta^2+\gamma^{-2}-\chi_0'} - \frac{1}{\theta^2+\gamma^{-2}}\right)R_{INT}^{(s)}, \qquad (4a)$$

$$R_{INT}^{(s)} = 2\varepsilon{\rm Re}\left(\left(\frac{\Omega_+^{(s)}}{\Delta^{(s)}}\cdot\frac{1-\exp(-ib^{(s)}\Delta_+^{(s)})}{\Delta_+^{(s)}} - \frac{\Omega_-^{(s)}}{\Delta^{(s)}}\cdot\frac{1-\exp(-ib^{(s)}\Delta_-^{(s)})}{\Delta_-^{(s)}}\right)\times \right.$$
$$\left.\times\left(\left(\frac{\exp(-ib^{(s)}(K^{(s)}/\varepsilon)) - \exp(ib^{(s)}(K^{(s)}/\varepsilon))}{(\xi^{(s)}-K^{(s)}-i\rho^{(s)}(1+\varepsilon)/2)\exp(-ib^{(s)}(K^{(s)}/\varepsilon)) - (\xi^{(s)}+K^{(s)}-i\rho^{(s)}(1+\varepsilon)/2)\exp(ib^{(s)}(K^{(s)}/\varepsilon))}\right)^*\right)\right),$$

where symbol "*" indicate the complex conjugation.

In formulas (2–3) the following notation is put to use:

$$\Delta^{(s)} = (\xi^{(s)}-K^{(s)}-i\rho^{(s)}(1+\varepsilon)/2)\exp(-ib^{(s)}\Delta_+^{(s)}) - (\xi^{(s)}+K^{(s)} - i\rho^{(s)}(1+\varepsilon)/2)\exp(-ib^{(s)}\Delta_-^{(s)}),$$

$$\Omega_\pm^{(s)} = \varepsilon\left((\sigma^{(s)}-i\rho^{(s)})\cdot\exp(-ib^{(s)}\Delta_\mp^{(s)}) + \Delta_\pm^{(s)}\right),$$

$$\Delta_\pm^{(s)} = (\xi^{(s)}\pm K^{(s)})/\varepsilon - \sigma^{(s)} + i\rho^{(s)}(\varepsilon-1)/2\varepsilon,$$

$$K^{(s)} = \sqrt{\xi^{(s)2}-\varepsilon-i\rho^{(s)}((1+\varepsilon)\xi^{(s)}-2\kappa^{(s)}\varepsilon)-\rho^{(s)2}\left((1+\varepsilon)^2/4-\kappa^{(s)2}\varepsilon\right)},$$

$$\xi^{(s)}(\omega) = \eta^{(s)}(\omega) + \frac{1+\varepsilon}{2\nu^{(s)}},$$

$$\eta^{(s)}(\omega) = \frac{\sin^2\theta_B}{V^2C^{(s)}}\frac{gT}{|\chi_b'-\chi_a'||\sin(ga/2)|}\left(1-\frac{\omega(1-\theta\cos\varphi\cot\theta_B)}{\omega_B}\right)$$

$$\nu^{(s)} = \frac{2C^{(s)}|\sin(ga/2)|}{g}\left|\frac{\chi_b'-\chi_a'}{a\chi_a'+b\chi_b'}\right|,$$

$$\rho^{(s)} = \frac{a\chi_a''+b\chi_b''}{|\chi_b'-\chi_a'|C^{(s)}}\frac{g}{2|\sin(ga/2)|},$$

$$\kappa^{(s)} = \frac{2C^{(s)}|\sin(ga/2)|}{g}\left|\frac{\chi_b''-\chi_a''}{a\chi_a''+b\chi_b''}\right|$$

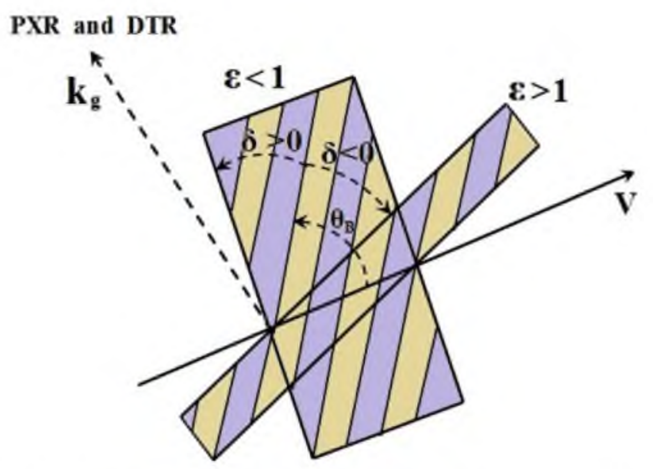

Fig. 2. The asymmetric ($\varepsilon < 1$, $\varepsilon > 1$) reflection of the radiation waves from target surface.

$$b^{(s)} = (L/\sin(\theta_B + \delta))/2L^{(s)}_{ext},\ \varepsilon = \sin(\theta_B - \delta)/\sin(\theta_B + \delta),$$
$$P^{(1)} = \sin\varphi,\ P^{(2)} = \cos\varphi. \tag{5}$$

When $s = 1$ and $\tau = 2$, the spectral-angular density (2–4) describes the σ-polarized fields and while $s = 2$ then π-polarized ones, In this case $\tau = 2$ if $2\theta_B < \pi/2$, and $\tau = 1$ otherwise.

The parameter $b^{(s)}$ is equal to ratio of half of the electron pass in the plate $L_e = L/\sin(\theta_B + \delta)$ to the length of extinction of X-rays in periodic layered medium $L^{(s)}_{ext}$.

The parameter $\nu^{(s)}$, which takes a value in the interval $0 \leqslant \nu^{(s)} \leqslant 1$, describes the degree of the reflection of the field from periodic layered structure. The value of $\nu^{(s)}$is determined by the character of the interference of the waves reflected from different layers: constructive (when $\nu^{(s)} \approx 1$) or destructive ($\nu^{(s)} \approx 0$). The parameter $\rho^{(s)} = L^{(s)}_{ext}/L_{abs}$ characterizes the degree of the X-ray wave absorption in periodic medium and is equal to the ratio of extinction length $L^{(s)}_{ext} = \frac{1}{2C^{(s)}\omega}\frac{gT}{|\sin(ga/2)||\chi'_b - \chi'_a|}$ to absorption length $L_{abs} = T(\omega|a\chi''_a + b\chi''_b|)^{-1}$ of X-ray in periodic layered structure.

The parameter $\kappa^{(s)}$ defines the manifestation degree of the dynamic effect of anomalously weak photoabsorption (Borrmann effect) in passage of X-ray photon through a artificial multilayered periodic structure. The necessary condition of Bormann effect manifestation for the periodic layered target as well as in the single crystal one is $\kappa^{(s)} \approx 1$.

The parameter ε can be presented as $\varepsilon = \sin(\theta_B - \delta)/\sin(\theta_B + \delta)$, where $\delta$is the angle between the entrance surface of the target and the crystallographic plane. For a fixed value of θ_B, the quantity ε determines the orientation of the target entrance surface related to reflecting layers (Fig. 2). When the angle $(\theta_B + \delta)$ of the electron incidence on the target decreases the parameter δ becomes negative and then grows by module (in limiting case$\delta \to -\theta_B$), that leads to the increase of ε. On the contrary, when incidence angle increases the value of ε decreases.

$$\sigma(\theta,\gamma) = \frac{gT}{2\cdot|\sin(ga/2)||\chi'_b - \chi'_a|}\cdot(\theta_\perp^2 + \gamma^{-2} + |a\chi'_a + b\chi'_b|/T),$$
$$\xi(\omega) = \frac{gT\sin^2\theta_B}{|\sin(ga/2)||\chi'_b - \chi'_a|}\cdot\left(1 - \frac{\omega}{\omega_B}\right) + \frac{1+\varepsilon}{2\nu^{(1)}},\ b^{(1)} = \frac{2\omega_B|\sin(ga/2)||\chi'_b - \chi'_a|}{gT\sin(\theta_B+\delta)}L,\ \theta_\perp = \theta\sin\varphi \tag{8}$$

3. Thin non-absorptive target

Let us consider the target made in form of a plate of such a thickness L, that the length of the electron path in the plate L_e will be bigger than the extinction length $L^{(s)}_{ext}$. In this case the condition of $b^s \gg 1$ will be fulfilled, what is the condition of dynamic effects manifestation in the coherent X-radiation exited by relativistic electron in periodic layered medium. In this case the condition of $b^s \gg 1$ will be fulfilled, what is the condition of dynamic effects manifestation in the coherent X-radiation exited by the relativistic electron in periodic layered medium.

On the other hand, we will consider the target enough thin to ignore the influence of the effect of photon absorption in this layered structure and more brightly reveal the effects of the dynamical diffraction. For this goal we will impose the additional condition on the target thickness, namely, let the maximal length of the diffracted photon path in the target $L_{\max f} = L/\sin(\theta_B - \delta)$ will be considerably less than absorption length L_{abs}:

$$2\frac{b^{(s)}\rho^{(s)}}{\varepsilon} = \frac{L_{\max f}}{L_{abs}} << 1 \tag{6}$$

Let us consider the σ- polarized waves ($s = 1$) and assume that $\rho^{(s)} = 0$, then in accordance with (9) we will obtain the expression for spectral-angular density of PXR in periodic layered medium for the case of a thin target:

$$\omega\frac{d^2N^{(1)}_{\rm PXR}}{d\omega d\Omega} = \frac{e^2}{\pi^2}\frac{\theta_\perp^2}{(\theta_\perp^2 + \gamma^{-2} + |a\chi'_a + b\chi'_b|/T)^2}R_{\rm PXR}, \tag{7a}$$

$$R_{\rm PXR} = R^{(1)}_{\rm PXR} + R^{(2)}_{\rm PXR} + R^{(uHT)}_{\rm PXR}, \tag{7b}$$

$$R^{(1,2)}_{\rm PXR} = \frac{(\xi \pm \sqrt{\xi^2 - \varepsilon})^2}{\xi^2 - \varepsilon + \varepsilon\sin^2(b^{(1)}(\sqrt{\xi^2 - \varepsilon}/\varepsilon))} \times \frac{\sin^2((b^{(1)}/2)((\xi \pm \sqrt{\xi^2 - \varepsilon})/\varepsilon - \sigma))}{((\xi \pm \sqrt{\xi^2 - \varepsilon})/\varepsilon - \sigma)^2}, \tag{7c}$$

$$R^{(INT)}_{\rm PXR} = \frac{\varepsilon}{\xi^2 - \varepsilon + \varepsilon\sin^2(b^{(1)}(\sqrt{\xi^2 - \varepsilon}/\varepsilon))} \times \frac{\cos(b^{(1)}(\sqrt{\xi^2 - \varepsilon}/\varepsilon))(\cos(b^{(1)}(\xi/\varepsilon - \sigma)) - \cos(b^{(1)}(\sqrt{\xi^2 - \varepsilon}/\varepsilon))}{(\xi/\varepsilon - \sigma)^2 + (\varepsilon - \xi^2)/\varepsilon^2}. \tag{7d}$$

Into formulas (7) the following natation is put to use

One can see that the PXR spectral density in (7a) is presented as a sum of the contribution of two generated in layered medium X-ray waves $R^{(1)}_{\rm PXR}$, $R^{(2)}_{\rm PXR}$ and the summand $R^{(INTT)}_{\rm PXR}$, which is the result of the interference of these waves.

Now from (3) we will obtain the formulas describing the spectral-angular density of DTR and also the summand resulting from the DTR:

$$\omega\frac{d^2N^{(1)}_{\rm DTR}}{d\omega d\Omega} = \frac{e^2}{\pi^2}\theta_\perp^2\left(\frac{1}{\theta_\perp^2 + \gamma^{-2}} - \frac{1}{\theta_\perp^2 + \gamma^{-2} + |a\chi'_a + b\chi'_b|/T}\right)^2 R_{\rm DTR}, \tag{9a}$$

$$R_{\mathrm{DTR}}=\frac{\varepsilon^2}{\xi^2-(\xi^2-\varepsilon)\coth^2(b^{(1)}(\sqrt{\varepsilon-\xi^2}/\varepsilon))}, \tag{9b}$$

The obtained expressions (7) and (9) are the main results of the present work. They allow investigating the spectral-angular characteristics of coherent X-radiation generated by relativistic electron in periodic layered medium in Bragg geometry with taking to account the manifestation of the dynamical diffraction effects.

4. Analysis of the radiation spectral-angular density

The contribution of the first $R^{(1)}_{\mathrm{PXR}}$ or/and second $R^{(2)}_{\mathrm{PXR}}$ branches of X-ray waves generated in the target will be considerable if the corresponding denominator in (7c) or/and (7d) can be vanish, i.e. the following equation have solution:

$$(\xi(\omega)+\sqrt{\xi(\omega)^2-\varepsilon})/\varepsilon-\sigma=0 \tag{10a}$$

$$(\xi(\omega)-\sqrt{\xi(\omega)^2-\varepsilon})/\varepsilon-\sigma=0 \tag{10b}$$

It can be proved, that the contribution of the first branch $R^{(1)}_{\mathrm{PXR}}$ in the spectrum will be more significant than of the second one $R^{(2)}_{\mathrm{PXR}}$. The contribution of the second branch $R^{(2)}_{\mathrm{PXR}}$ into the radiation can be comparable with $R^{(1)}_{\mathrm{PXR}}$ only under the condition of small values of asymmetry parameter $\varepsilon \ll 1$, but under this condition the yield of PXR will be very small.

Let us consider the PXR spectrum density under different observation angles. In Fig. 3 the curves are presented which describe the PXR spectrum of the relativistic electron with energy 500 MeV crossing the periodic layered beryllium-silicon medium, derived by formulas (7a) and (7c) for values of parameter pointed in the figure. It is seen from Fig. 3 that under decrease of observation angle $\theta_\perp$ the PXR spectrum shifts in the direction of frequency region of total external reflection of the radiation (extinction). The region of total reflection is determined by the following inequality:

$$-\sqrt{\varepsilon}<\xi(\omega)<\sqrt{\varepsilon} \tag{11}$$

Now let us consider the spectral density of DTR under different observation angles. In Fig. 4 the curves describing the DTR spectral density calculated by formulas (9a) and (9b) are presented under the same value of parameters as in Fig. 3. One can see in Fig. 4 that the DTR spectrum amplitude significantly depends on the observation angle $\theta_\perp$, but the width of the total reflection region (11) remains without of change because the spectral function $\xi(\omega)$ not depends on $\theta_\perp$.

The analysis of the dependence of the radiation spectral density on the ratio of the thicknesses of the reflecting layers a and b is of special interest to optimize the efficiency of the layered radiator.

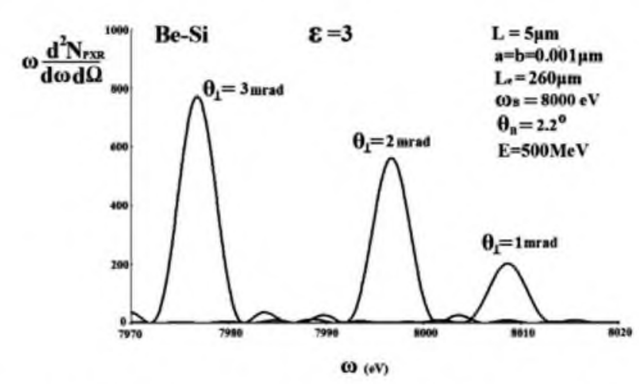

Fig. 3. Relativistic electron PXR in a periodic layered under different observation angles.

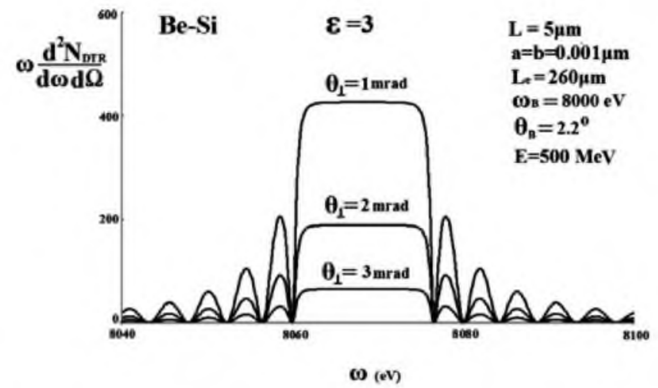

Fig. 4. Relativistic electron DTR in a periodic layered under different observation angles.

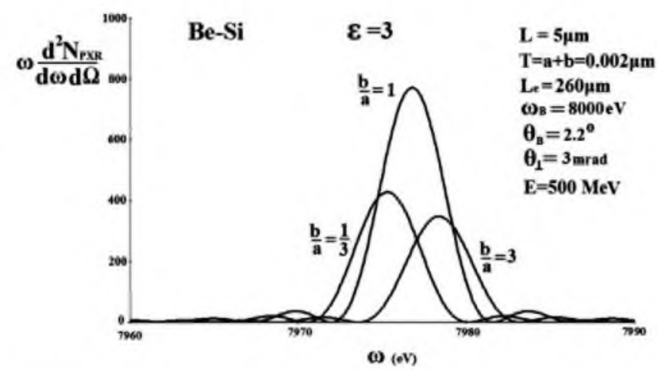

Fig. 5. The spectrum of PXR for different values of ratio of layers depth $\frac{b}{a}$ under fixed value of $T=a+b$.

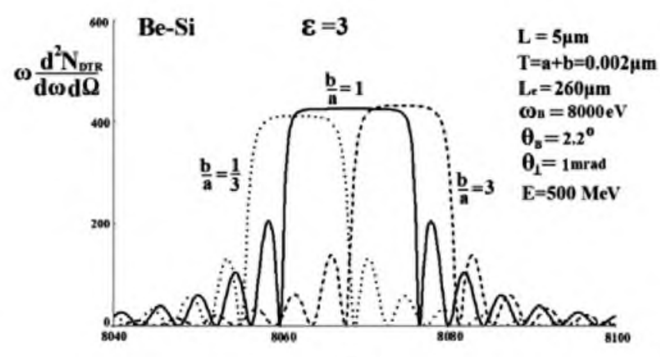

Fig. 6. The spectrum of DTR for different values of ratio of layers depth $\frac{b}{a}$ under fixed value of $T=a+b$.

The distributions of the DTR and PXR spectral densities, calculated for constant sum $T=a+b$ and different values of the ratio $\frac{b}{a}$, are curved in Fig. 5 and Fig. 6. It follows from these figures that for both the radiation mechanisms the spectral density is maximal when $\frac{b}{a}\approx 1$. It results from the fact that parameter $\nu^{(1)}$ (see (5)) which defines the reflection degree of the X-radiation waves on the periodic layered structure, determining by the interference of the waves reflected from different layers of the structure, for considered structure Be-Si is maximal when $\frac{b}{a}\approx 1$.

Let us analyze the parameter ν, which is proportional to the angular density of the radiation, in the dependence on the value of the ratio a/b. For this we represent it in the following view:

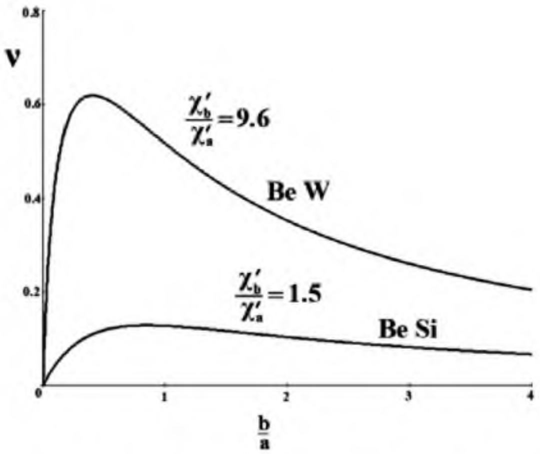

Fig. 7. The dependence of the degree of X-ray waves reflection (ν) from periodic layered Be-W and Be-Si targets on the ratio $\frac{b}{a}$.

$$\nu = \frac{1}{\pi}\left(1+\frac{b}{a}\right)\left|\frac{\chi_b'}{\chi_a'}-1\right|\sin\left(\frac{\pi}{1+\frac{b}{a}}\right)\left(1+\frac{b}{a}\frac{\chi_b'}{\chi_a'}\right)^{-1} \qquad (12)$$

The curves of the dependence $\nu(\frac{b}{a})$ calculated by formula (12) for two pairs of layered media are presented in Fig. 7. As it following from this figure, for more dense the second medium, containing the amorphous layers of tungsten W, the degree of the reflection of the radiation turns out higher and the maximal value of the radiation amplitude shifts to the direction of the lesser value of the ratio $\frac{b}{a}$. This is due to the dependence of $\xi(\omega)$ on this ratio.

Let us consider how the asymmetry of the reflection of the X-ray waves from the entrance surface of the target influences the PXR and DTR. The increase of parameter ε, i.e. the decrease of the angle of the incidence of the electron on the target surface, leads to the considerable increase of the spectral line width of PXR in periodic layered structure. This is due to the fact that the frequency dependence of the resonance condition (10a) becomes weaker with increasing parameter ε. In the case of DTR the increase of ε leads to increase of both the spectral amplitude and the width of the region of the total external reflection. The increase of the PXR and DTR spectral density under increase of asymmetry parameter ε leads to considerable increase of angular density these radiations. To demonstrate this fact we will use the formula, describing the angular radiation density:

$$\frac{dN_{\mathrm{PXR}}}{d\Omega} = \frac{e^2}{\pi^2}\frac{\theta_\perp^2}{\left(\theta_\perp^2+\gamma^{-2}+|a\chi_a'+b\chi_b'|/T\right)^2}\int_{-\infty}^{+\infty} R_{\mathrm{PXR}}\frac{d\omega}{\omega}, \qquad (13)$$

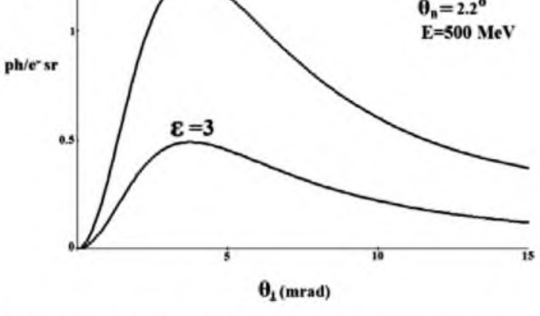

Fig. 8. Angular density of PXR under different reflection asymmetry (parameter ε).

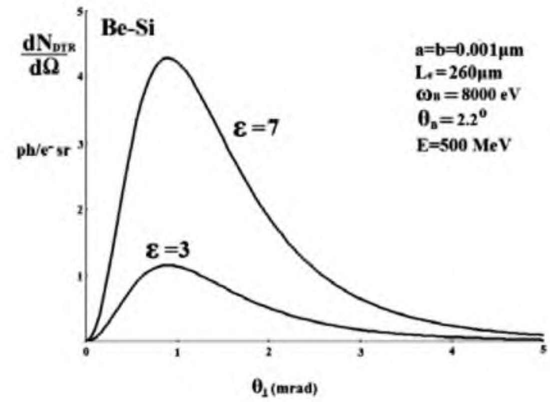

Fig. 9. Angular density of DTR under different reflection asymmetry (parameter ε).

$$\frac{dN_{\mathrm{DTR}}}{d\Omega} = \frac{e^2}{\pi^2}\theta_\perp^2\left(\frac{1}{\theta_\perp^2+\gamma^{-2}}-\frac{1}{\theta_\perp^2+\gamma^{-2}+|a\chi_a'+b\chi_b'|/T}\right)^2 \times \int_{-\infty}^{+\infty} R_{\mathrm{DTR}}\frac{d\omega}{\omega}. \qquad (14)$$

The curves in Figs. 8 and 9 calculated by formulas (17) and (18) show that the increase of asymmetry parameter ε leads to significant growth of PXR and DTR angular density of the radiations.

5. Conclusion

In the present work a theory of the coherent X-radiation generated by the relativistic electron crossing a periodic layered medium in Bragg scattering geometry is build up. By analogy with the coherent radiation of the relativistic electron in a single crystal the radiation in periodic layered medium is considered as the sum of the contribution of two mechanisms: parametric X-radiation (PXR) and diffracted transition radiation (DTR). Based on two-wave approximation of dynamic diffraction theory the expression for spectral-angular characteristic PXR and DTR of relativistic electron in periodic layered medium are derived.

The dependences of the spectral-angular density of the radiation on the ratio of the thicknesses of the alternating layers in the target and on the asymmetry of the electromagnetic field reflection from the layered structure are revealed. Particularly, there are shown that for fixed Bragg angle the decrease of the electron incidence angle (i.e. increase of asymmetry parameter ε) leads to considerable growth of the PXR spectrum width and accordantly to growth of angular density of the radiation. It is shown that this effect is not connected with the absorption. This fact opens up the possibility of creating an intense quasi-monochromatic X-ray source based on the interaction of relativistic electrons with artificial periodic layered structure.

The growths of the frequency range of total external reflection as well as the appropriate growth of DTR spectrum width under decrease of the angle of the electron incident on the target are revealed which is companied by the considerable increase of angular density of DTR.

Thus we can conclude that, as well as in the single crystal, the dynamic effects in the coherent X-radiation associated with the asymmetry in the reflection of coulomb field of relativistic electron from the entrance surface of the target brightly manifest itself also in the periodic layered media.

The possibilities of the creation of an intensive quasi-monochromatic X-ray source on the basis of the interaction of relativistic electrons with the periodical multilayered medium are pointed out.

References

[1] M.L. Ter-Mikaelian, High-Energy Electromagnetic Process in Condensed Media, Wiley, New York, 1972.
[2] M.A. Piestrup, D.G. Boyers, C.I. Pincus, et al., Phys. Rev. A 45 (1992) 1183.
[3] B. Pardo, J.-M. Andre, Phys. Rev. E 65 (2002) 036501.
[4] N.N. Nasonov, V.V. Kaplin, S.R. Uglov, M.A. Piestrup, C.K. Gary, Phys. Rev 68 (2003) 3604.
[5] N.N. Nasonov, V.V. Kaplin, S.R. Uglov, V.N. Zabaev, M.A. Piestrup, C.K. Gary, Nucl. Instr. Meth. B 227 (2005) 41.
[6] G.M. Garibian, C. Yang, J. Exp. Theor. Phys. 61 (1971) 930.
[7] V.G. Baryshevsky, I.D. Feranchuk, J. Exp. Theor. Phys. 61 (1971) 944.
[8] V.G. Baryshevsky, I.D. Feranchuk, J. Phys. (Paris) 44 (1983) 913.
[9] A. Caticha, Phys. Rev. A 40 (1989) 4322.
[10] V.V. Kaplin, S.R. Uglov, V.N. Zabaev, M.A. Piestrup, C.K. Gary, N.N. Nasonov, M.K. Fuller, Appl. Phys. Lett. 76 (2000) 3647.
[11] S.V. Blazhevich, I.V. Kolosova, A.V. Noskov, J. Exp. Theor. Phys. 114 (2012) 547.
[12] S. Blazhevich, A. Noskov, Il. Nuovo Cimento 34C (2011) 231, http://dx.doi.org/10.1393/ncc/i2011-10922-x.
[13] S. Blazhevich, I. Kolosova, A. Noskov, J. Phys. Conf. Ser. 357 (2012) 012016, http://dx.doi.org/10.1088/1742-6596/357/1/012016.
[14] S. Blazhevich, A. Noskov, Il. Nuovo Cimento 34C (2011) 243, http://dx.doi.org/10.1393/ncc/i2011-10970-2.
[15] S. Blazhevich, A. Noskov, Charged and neutral particles channeling phenomena (Channeling 2008), in: Proceedings of the 51st Workshop of the INFN Eloisatron Project – Erice, Italy, October 25–November 1, 2008, World Scientific, Erice, 2010, pp. 632–660.