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ON THE INFLUENCE OF CHANNELING OF HIGH-ENERGY ELECTRONS ON THE SPECTRAL PROPERTIES OF THEIR RADIATION IN A CRYSTAL

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We consider some features of motion and radiation of relativistic electrons in thin crystals at small values of the particle angle of incidence on the crystal relative to a crystallographic axis when the channeling effect takes place. The main attention is paid to peculiarities of radiation spectral characteristics for the particles which move in different modes, such as: over-barrier motion, axial channeling, planar channeling. It was shown that for small values of the incidence particle angle the positions of maxima of the radiation spectra for the above-barrier and channeling modes differ. This is due to the difference in the character of motion of particles in these modes.

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The phenomenon of channeling, when the charged particles move inside a crystal along the channels formed by parallel atomic strings or planes, was predicted by Robins and Oen [1] in the 1960s. Since then, the interest to studying the influence of this phenomenon on physical processes during the passage of charged particles through crystals has not waned.

In the present paper we would like to pay attention to another interesting effect associated with manifestation of channeling of relativistic electrons in the spectral properties of their radiation in a crystal, which takes place in radiation by channeled particles and by above-barrier particles.

Since the probability of particle capture into the channeling mode decreases with the increase of the angle ψ of particle incidence on the crystal relative to a crystallographic axis, we will first consider the influence of channeling on radiation spectral characteristics for the particle incidence angle $\psi=0$, when this influence is the most pronounced.

The consideration is based on the numerical simulation of relativistic electron scattering process in the crystal, taking into account both coherent and incoherent effects in scattering associated with thermal spread of atomic positions in the crystal lattice [2].

When relativistic electrons move in a crystal at small angles relative to a crystallographic axis, a certain part of these particles move in the channeling mode.

As an example, in Fig. 1 we present the dependence of fraction of channeled electrons with the energy of 1 GeV in the case of their motion in a Si crystal of 100 μm thickness near <100> axis for the angle $\psi=0$ of the particle incidence on the crystal.

From the simulation results it follows that despite the fact that the particles entered the crystal at $\psi=0$, due to rechanneling, the particles captured into the planar channeling mode may appear.

The obtained results show that the part of axially channeled electrons decreases with the increase of their path in the crystal, while the part of planar channeled electrons does not decrease with the increase of their path, remaining quite low.

Let us now proceed to the study of influence of channeling on some aspects of the spectral properties of radiation by relativistic electrons in the crystal. The consideration is carried out on the basis of numerical simulation of radiation by relativistic electrons in a crystal [3]. Calculations of the electron radiation spectra were carried out separately for above-barrier and channeled particles. A conventional calculation for all the particles together has been performed as well.

It should be noted that at $\psi=0$ the contribution to radiation by the planar channeled particles is very small due to a little fraction of such particles, as well as due to a weaker potential in the plane.

The results of simulation of radiation by electrons with 200 MeV and 1 GeV energies moving near <100> axis of a 100 μm Si crystal and having the angle of incidence on the crystal $\psi=0$, are presented in Fig. 2. A separation of the spectra from above-barrier (or without channeling) and channeled particles is performed.

The obtained results show that in the considered case the channeled particles make a significant contribution to the radiation, which leads to a change in the position of the spectrum maximum. Note that the positions of the maxima of the spectra for the above-barrier and channeled particles differ. It is due to the fact that values of the oscillation periods of trajectories for these groups of particles are different.

For channeled particles the period of oscillations of their trajectories is determined by the average value of the period of their rotation around the axis (at ε=200 MeV – 0.138 μm, at ε=1 GeV – 0.39 μm), while for the above-barrier particles it is determined by the average distance between different atoms strings of the crystal L_a, defined by the formula:

$$L_a=2R/\psi_c\ ,$$

where R is the radius of the atomic string; ψ_c is the critical angle of axial channeling. For above-barrier particles at ε=200 MeV L_a=0.222 μm, while at ε=1 GeV L_a=0.5 μm.

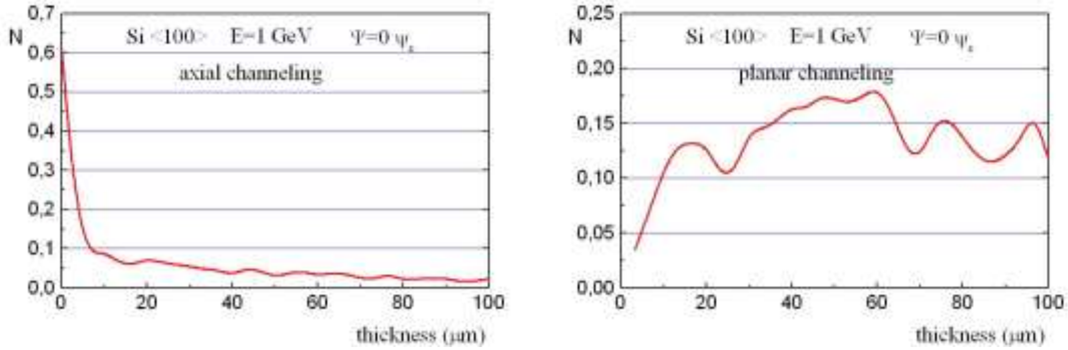
As the crystal thickness decreases, the relative contribution of channeled particles to radiation increases accordingly. This is shown in Fig. 3.

In this case, the contribution of channeled particle spectrum (blue lines) exceeds the contribution of above-barrier particle spectrum (green lines).

Let us now consider how the contribution of channeled particles in the crystal changes the radiation with the increase of the angle of particle incidence on the oriented crystal. The increase of ψ leads to the decrease of the part of axially channeled electrons in the crystal, while the part of planar channeled particles, on the contrary, increases due to rechanneling. Such redistribution of the channeled particle ratios affects the character of the channeled particle spectra. This is shown in Fig. 4.

The results of numerical simulation of radiation by 1 GeV electrons moving near <100> axis of 100 μm Si crystal and having the angles of incidence on the crystal $\psi=1\psi_c$ and $\psi=2\psi_c$, are presented in Fig. 5. The separation of spectra for above-barrier and channeled particles is performed.

These results also show that for angles ψ greater than ψ_c the contribution of channeled particles to the radiation does not lead to a significant change in the position of the maximum of the radiation spectrum.



a *b*

Fig. 1. Dependence of the fraction of 1 GeV electrons which move in the modes of axial (a) and planar (b) channeling on the depth of their penetration into the Si crystal with the axial orientation relative to the incident particle beam

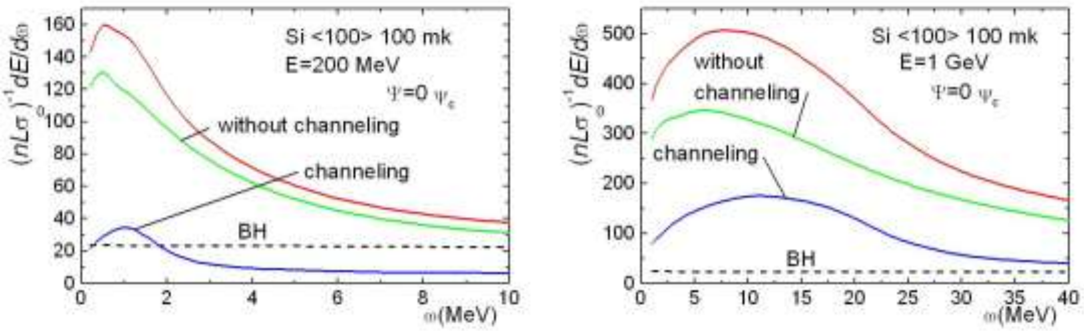


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Fig. 2. Radiation spectra for electrons with the energy ε=200 MeV (a) and ε=1 GeV (b) moving in a 100 μm Si crystal, impinging at angle ψ =0 to <100> axis; here are the total spectrum (red), spectrum for above-barrier particles (green) and spectrum for channeled particles (blue). Solid lines are simulation results, dashed lines are the Bethe-Heitler spectra; L is the target thickness, n is the atomic density, $\sigma_0 = Z^2 e^6 m^{-2}$

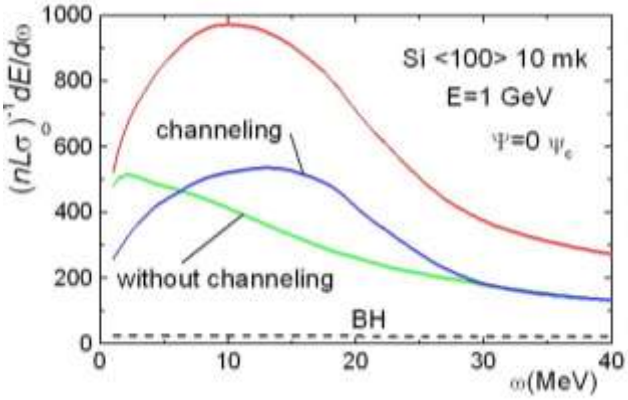
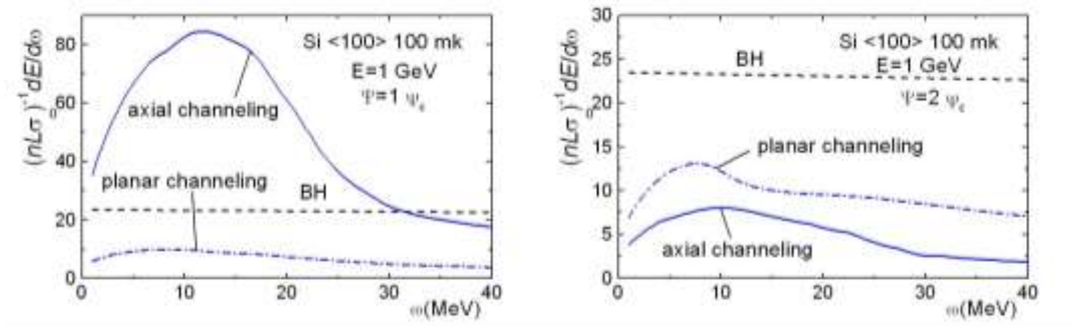
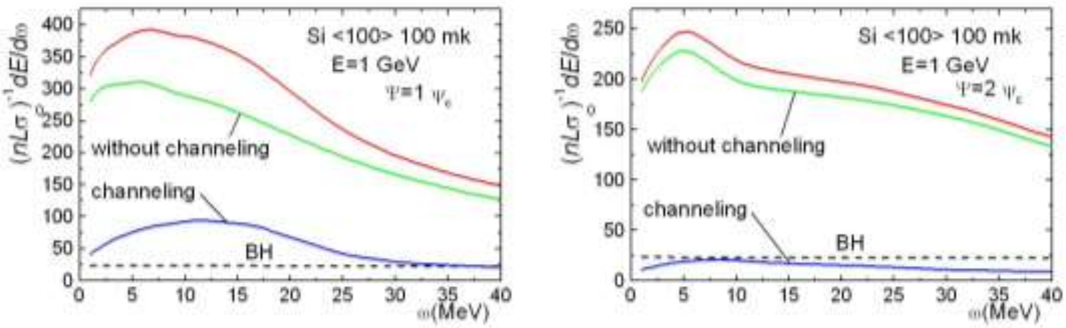


Fig. 3. The same as in Fig. 2, but for ε=1 GeV in a Si crystal of 10 μm thickness



a *b*

Fig. 4. The same as in Fig. 2, but for ε=1 GeV in 100 µm Si crystal at ψ=1ψ$_c$ (a) and ψ=2ψ$_c$ (b); solid lines - the spectrum of axially channeled particles, dashed-dot lines - the spectrum of planar channeled particles



a *b*

Fig. 5. The same as in Fig. 2, but for ε=1 GeV in 100 µm Si crystal at ψ=1ψ$_c$ (a) and ψ=2ψ$_c$ (b)

CONCLUSIONS

On the basis of numerical simulation of relativistic electron radiation in thin oriented crystals, we considered the spectral properties of radiation at small values of the particle incidence angle ψ on the crystal relative to a crystallographic axis, when the channeling effect occurs.

The main attention was focused on the radiation spectra of particles with different modes of motion in the crystal, particularly, for above-barrier and channelling modes.

It was shown that for small values of ψ the positions of maxima of the radiation spectra for the above-barrier and channeling modes differ. This is due to the difference in the character of motion of particles in these modes.

ACKNOWLEDGEMENTS

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ВПЛИВ ЯВИЩА КАНАЛЮВАННЯ ЕЛЕКТРОНІВ ВИСОКИХ ЕНЕРГІЙ НА СПЕКТРАЛЬНІ ВЛАСТИВОСТІ ЇХНЬОГО ВИПРОМІНЮВАННЯ В КРИСТАЛІ

В.І. Трутень

Розглянуто особливості руху та випромінювання релятивістських електронів у тонких кристалах при малих значеннях кута вльоту частинок у кристал по відношенню до кристалографічної осі, коли має місце ефект каналювання. Основна увага звертається на особливості спектральних характеристик випромінювання частинок, рух яких відбувається у різних режимах, таких як надбар'єрний рух, рух при осьовому каналюванні, рух при площинному каналюванні. Показано, що при малих значеннях кута вльоту частинок у кристал по відношенню до кристалографічної осі положення максимумів у спектрах випромінювання при надбар'єрному режимі та каналюванні відрізняються. Це пов'язано з різницею характеру руху таких частинок.