

SPECTRA OF COHERENT BREMSSTRAHLUNG AND RADIATION FORMED BY 0.8 GEV ELECTRONS MOVING NEAR THE AXIS AND PLANE OF DIAMOND CRYSTAL

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Spectra of coherent bremsstrahlung and radiation spectra of the electron moving near the axis and plane of diamond crystal have been measured using the electron beam of low intensity with 0.8 GeV energy. Experimental data are compared with calculations based on the coherent bremsstrahlung theory.

PACS: 29.27.Fh

1. INTRODUCTION

The beams of coherent bremsstrahlung (CB) found broad application in experiments on nuclear and elementary particles physics [1]. These beams are generated by relativistic electrons in monocrystalline photon targets when the electron incidence angle towards crystal axes are rather large, $\psi \gg \psi_c$ (ψ_c is the critical angle of axial channeling. For the diamond crystal and electron energy $E_0 \sim 1$ GeV $\psi_c \approx 0.3$ mrad). Owing to periodicity of atom positions in a crystal lattice there appear interference peaks in CB spectra in which the radiation intensity significantly exceeds that of electrons in an amorphous substance. Besides the radiation in the region of the peak has rather high linear polarization. Due to a high Debye temperature, perfect crystal lattice and small atomic number the monocrystalline targets from diamond crystals ensure the highest operational parameters of CB beams [1].

The spectra of CB radiation and polarization are well described by the theory based on the Born approximation [2,3]. According to the theory the CB cross section can be presented as a sum:

$$d\sigma_{\text{kti}} = d\sigma_{\text{coh}} + d\sigma_{\text{am}},$$

where $d\sigma_{\text{coh}}$ is the coherent part of the CB cross section depending on the crystal orientation towards the direction of the electron beam; $d\sigma_{\text{am}}$ is the non-coherent (amorphous) part of the cross section which does not depend on the crystal orientation. So, the CB spectrum consists a sum of two parts: coherent part I_{int} with interference peak and usual bremsstrahlung I_{am} . The interference peak has a sharp upper bound and it is reduced smoothly in the low energy area. The radiation intensity in the peak drops with increasing angle ψ , and its position displaces into the area of high energies and for a rather large ψ the peak is not observed.

There are also other crystal orientations towards an incoming electron beam, with which the generation of intensive gamma radiation is observed, for example, when the channeling modes or above-barrier electron movement are realized [4,5]. So, if incoming electrons drop onto the crystal along crystalline planes, but at large angles to crystal axes, $\psi \gg \psi_c$, the electron movement in the crystal is determined by an average

interplanar potential. Then the conditions for channeling or above-barrier electron movement near the plane of crystal take place. This results in appearance of an interference maximum in the low-energy area of radiation spectrum, $\sim 7-10$ MeV, for the energy of incoming electrons $E_0 \sim 1$ GeV. Its intensity for a non-collimated radiation is $\sim 3-5$ times higher, than the radiation intensity in amorphous medium [6]. The emergence of this maximum is conditioned by the periodicity of electron movement in the average potential of crystal planes. As the period corresponding to the electron movement in the interplanar potential does not depend on the angle ψ , the position of this interference peak does not depend on ψ too. Radiation of this type usually is called as plane channeling radiation.

One more possibility for generation of the intensive gamma radiation is opened, when the electrons drop onto the crystal along one of the main close-packed axes, $\psi \leq \psi_c$. In this case also observed is the significant enhancement of radiation intensity in the range of low energies. It is connected with effects of axial channeling or axial above-barrier electron movement. The spectrum of this radiation also has a maximum which takes place in the region of $\sim 20-30$ MeV for the energy of incoming electrons $E_0 \sim 1$ GeV and its intensity is ~ 20 times higher than the radiation intensity in amorphous medium [6]. When the angle of incidence towards the axis increases, the emission power in this energy range drops. Radiation of this type usually is called as axis channeling radiation. The movement of ~ 1 GeV electrons in the crystal and their radiation spectra in these cases can be described within the framework of classical electrodynamics [4,5].

Research on spectral characteristics of radiation, for orientations corresponding to CB generation, planar or axial channeling, was conducted, as a rule, in diverse experiments using the crystals of a various thickness and different atomic number. It is useful to compare spectral characteristics of these types of radiation obtained in the same experimental conditions. In the present paper the results of such measurements are given for the incoming electron energy $E_0 = 0.8$ GeV and diamond crystal 0.03 cm thick.

2. EXPERIMENTAL LAYOUT

The measurements were carried out on the electron beam of low intensity at the Kharkov 2 GeV linear accelerator. The layout of the experiment is shown in Fig. 1. After passing through the crystal target (1) the electrons were deflected by a cleaning magnet (2) and entered a beam dump (3). The photon beam, produced in the crystal, was passed through a formation system composed of three rectangular lead collimators (5,6,9) and cleaning magnets (2,7,10). In front of the last collimator (9) a filter (8) from LiH $1.7X_0$ thick was placed. The collimation angle of the gamma radiation was $\theta_k \approx 0.3\theta_\gamma$ ($\theta_\gamma = m/E_0$, m - is the electron mass) and ensured a size of a gamma beam on a detector (11) 3×3 cm.

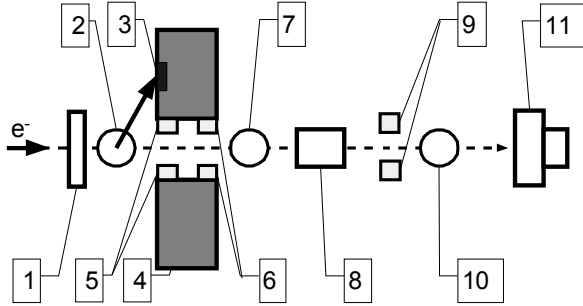


Fig. 1. Experimental layout: 1-diamond crystal; 2,7,10- cleaning magnets; 3-beam dump; 4-shielding; 5,6,9- collimators; 8-LiH filter $1.7X_0$ thick; 11- NaJ detector.

The photons were detected in an counting mode by the NaJ(Tl) counter 20 cm in diameter and 20 cm in thickness. The intensity of the electron beam was selected such that the load of the detector did not exceed 10 counts/s. The system of producing and forming the electron beam of a low intensity and controlling its parameters, as well as the procedure of measurements were described in [6,7].

The measurements of CB spectra were carried out for orientations, when the main contribution to the CB cross section was introduced by one point of the reciprocal lattice (2,2,0). The angles of crystal orientation θ and α , respective to direction of the electron beam, unambiguously determine the energy of the interference peak E_γ^p in the CB spectrum. θ is the angle between the electron momentum and axis $B1 = \langle 110 \rangle$ of diamond crystal, α is the angle between planes $(P_0, B1)$ and $(B1, B2)$, where the axis $B2 = \langle 110 \rangle$. In experiment the values of angles θ and α were selected in such a manner that the interference maxima corresponded to energies $E_\gamma^p = 30, 60, 100, 140$ MeV. The values of the relative energy $X = E_\gamma^p/E_0$ are 0.0375, 0.075, 0.125 and 0.175, respectively. The planar orientation was obtained when values of the angles were $\alpha = 0$ and $\theta = 75$ mrad that corresponded to electron movement in the plane (001) of the diamond crystal. The axial orientation was obtained for the angle $\theta = 0$, that corresponded to the electron movement along the axes $\langle 110 \rangle$.

3. RESULTS

In Fig. 2 the CB spectrum measured in the range of photons energies $0.02 \leq X \leq 0.75$ for the peak energy $E_\gamma^p = 100$ MeV is shown. The interference peak with the half-width ~ 38 MeV has a sharp upper bound with smooth lowering in the low-energy area practically up to zero energies as it is predicted by the CB theory. For energies higher than 250 MeV the interference part does not give any more contribution and the spectrum in this area has a form of a bremsstrahlung spectrum in amorphous substance. Usually, the intensity of the CB is evaluated by the excess β of radiation intensity in the CB maximum over the intensity of non-coherent part of radiation spectrum:

$$\beta = (d\sigma_{int} + d\sigma_{am}) / d\sigma_{am} = (I_{int} + I_{am}) / I_{am}.$$

For spectrum in Fig. 2 the excess is $\beta \sim 6$ and it is well described by the CB theory.

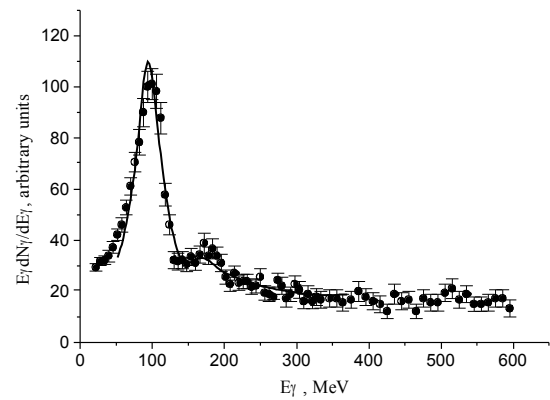


Fig. 2. CB spectrum for the 100 MeV energy peak. The curve is the calculation under the CB theory.

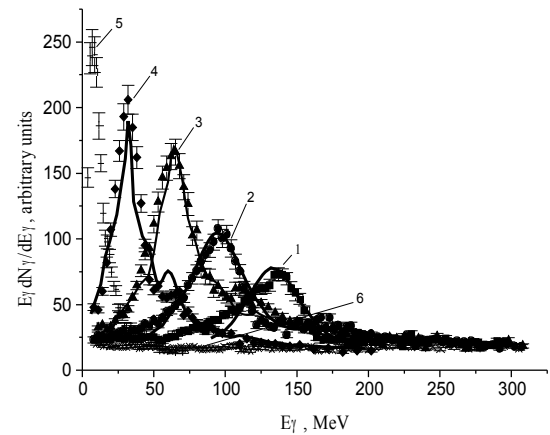


Fig. 3. CB spectra for energies of interference peak: 140 MeV (1), 100 MeV (2), 60 MeV (3), 30 MeV (4). (5)- planar orientation. (6)- Schiff spectrum. The curves are calculated under the CB theory.

In Fig. 3 the results of CB spectra measurements in the photon energy range $0.01 \leq X \leq 0.375$ for energies of interference maxima $E_\gamma^p = 30, 60, 100, 140$ MeV are shown. For comparison the spectra were normalized at the photon energy 300 MeV, where the radiation is

determined only by the non-coherent part, and the intensity does not depend on the crystal orientation.

It is seen, that the radiation intensity in CB maxima increases with decreasing energy of interference maxima. The magnitude of exceeding the maximum above the amorphous level increases from $\beta \approx 3.5$ to 10 with decreasing peak energy from $E_{\gamma}^p = 140$ MeV ($X=0.175$) to 30 MeV ($X=0.0375$). The high values of β are due to the strong collimation of the gamma radiation. In Fig. 3 shown are also the calculations of the CB spectra under the theory [2,3]. The theory describes well the experimental data for $X \geq 0.1$. For lower X the agreement is worsened because the angles of electron incidence onto the plane of crystal become already comparable with the critical angles of channeling. The results of calculation for the CB polarization under these conditions are shown in Fig. 4. It is seen, that the polarization of radiation is rather significant, namely 85% for $E_{\gamma}^p = 30$ MeV and 75% for 140 MeV. The large values of polarization are caused also by the strong collimation of radiation.

In Fig. 3 also shown is the spectrum for the case when incoming electrons drop onto the crystal along the crystalline plane (001) at large angle, $\psi = 75$ mrad, to the crystalline axis $\langle 110 \rangle$. For this orientation the maximum radiation is observed at the photon energy $E_{\gamma} \sim 7-8$ MeV and the value β increases up to 12.5. This maximum is not broad. At the energy $E_{\gamma} \sim 40$ MeV the radiation intensity decreases yet up to the amorphous level. This orientation gives a slightly larger intensity in the maximum, than CB. The radiation in the maximum at this orientation is also strong polarized, up to 80 % for the incoming electron energy $E_0 \sim 1$ GeV [8].

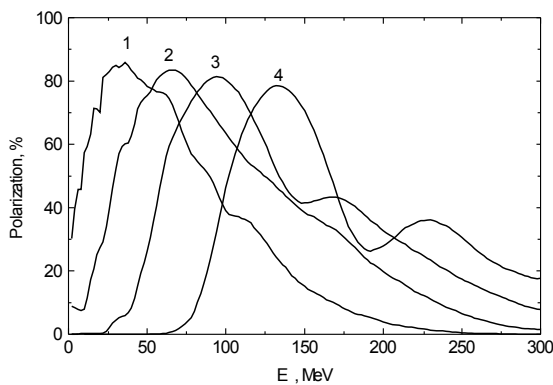


Fig. 4. Calculation of CB polarization for interference peak energies 30 (1), 60 (2), 100 (3), 140 (4) MeV.

The significant increase of the radiation intensity in the range of low energies is observed for axial orientation, when the electron beam drops onto the crystal along the axis $\langle 110 \rangle$, Fig. 5. For conditions of the given experiment the intensity maximum takes place at the photon energy $E_{\gamma} \sim 20$ MeV. The exceeding above the amorphous level is about $\beta \approx 70$, that is 5-6 times higher, than that of CB and planar orientation in this energy range. The radiation spectrum is broader and gets the amorphous level at $E_{\gamma} \sim 140$ MeV, however, the radiation in the maximum has not polarization.

Thus, the experimental measurements show that

there is a wide variety of possibilities to obtain intensive and polarized photon beams for studying photonuclear reactions in the area extended up to the pion threshold. The radiation intensity at the axial orientation exceeds the radiation intensity of other types of orientations by the order of magnitude. An essential circumstance is that the exceeding of the emission intensity in the maximum above the emission in amorphous medium at the axial orientation weakly depends on a thickness of crystal in the range up to $0.3X_0$ [9]. Therefore there is a possibility to increase the intensity of photon beams by increasing the crystal thickness.

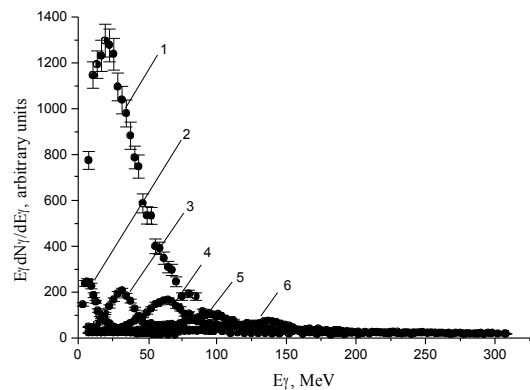


Fig. 5. Radiation spectra for various orientations: (1)- axial; (2)- planar; (3,4,5,6) CB spectra, for peak energies, 30, 60, 100 and 140 MeV, respectively.

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