X-ray source based on parametric and transition radiation of electrons

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An experimental investigation of a new type of source of hard (10–40 keV) x-rays, which are produced by passing 700-MeV electrons through a compound target (multifoil structure + crystal), was performed on Sirius synchrotron in Tomsk. It was shown that for a mosaic crystal the intensity of the diffracted resonance x-ray transition radiation is much higher than the intensity of the parametric x-ray radiation of the electrons. The angular distributions of these radiations are analyzed. The spectral densities of the transition radiation, diffracted transition radiation, and parametric x-ray radiation of the electrons are compared. © *1995 American Institute of Physics.*

Parametric x-ray radiation (PXR) of electrons is produced by the diffraction of the pseudophotons of the self-field of an electron moving in a crystal.[1] The PXR linewidth can be of the order of 10% or less. The PXR photons are emitted in the Bragg direction in a narrow cone with an angle of several γ^{-1}, depending on the characteristics of the crystal (γ is the relativistic factor of an electron). However, the intensity of the PXR radiation is low, approximately 10^{-5} photons per electron.

Transition x-ray radiation (TXR) is produced when an electron passes through the interface between two media with different permittivities.[2] The x-ray yield from a radiator consisting of several hundred thin foils can amount to several photons per electron. The TXR spectrum lies in the energy range up to $E_\gamma \simeq \hbar\omega_p\gamma$, where ω_p is the plasma frequency of the medium and the width of the spectral band of the radiation is equal to 50–80%, depending on the absorbing properties of the radiator material. The TXR photons are emitted into a cone with an angle of the order of γ^{-1} in the direction of motion of the electrons. If the thickness of the foils and the spacing between them in the layered structure are chosen in such a way that the TXR from the different foils of the radiator is emitted coherently, then so-called resonance TXR (RTXR) is observed. The angular spectral intensity of the RTXR increases as M^2, where M is the number of foils, and the

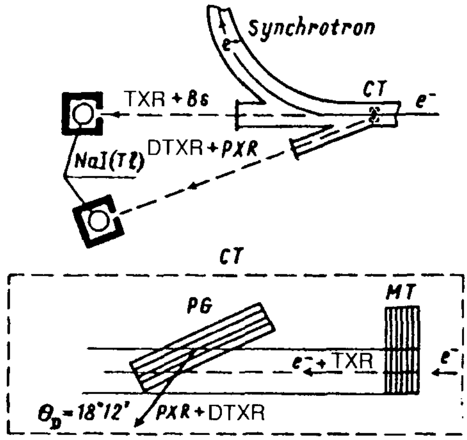

FIG. 1. Experimental arrangement: TXR — transition x-ray radiation, Bs — Bremsstrahlung, CT — compound target, DTXR — diffracted transition radiation, PXR — parametric x-ray radiation, PG — pyrolytic graphite crystal, MT — multifoil target.

cone angle of the radiation can be varied over a range of several γ^{-1}, depending on the parameters of the multifoil structure.

A new concept for obtaining intense, monochromatic, adjustable, and narrowly directed (at large angles to the electron beam) x-ray radiation using a compound target "multifoil structure + crystal" was proposed in Ref. 3 . In this case the RTXR generated in the multifoil structure is diffracted by the crystal and is emitted together with PXR in the Bragg direction. It is expected that the diffracted RTXR (DTXR) obtained in this case will possess positive qualities of RTXR (narrow beam, high intensity) and PXR (monochromaticity, large emission angles).

In the present letter we report the results of an experimental study of the characteristics of RTXR, PXR, and DTXR produced by electrons in a layered copper target, a pyrolytic graphite crystal, and a compound target. This study was performed in the internal beam of the Sirius synchrotron in Tomsk. The energy of the accelerated electrons was $E_e=700$ MeV. The characteristics of the synchrotron are described in detail in Ref. 4 . The results of the measurements were normalized with the aid of a detector of synchrotron radiation from accelerated electrons.

The experimental arrangement is shown in Fig. 1. The compound target (CT) consisted of a multifoil target (MT) based on copper foils and a pyrolytic graphite crystal (PG). The multifoil target consisted of nine 12-μm-thick copper foils separated from one another by a distance of 52 μm. The dimensions of the PG crystal prepared by the Union Carbide Company were $10\times6\times1.5$ mm. This crystal was previously used in Ref. 5 . The angle between the electron momentum and the crystallographic planes (200) was $\theta_B=9°06'$. The precedure for inserting and orienting the PG crystal in the electron beam is described in Ref. 5 . Either the PG crystal or the multifoil target could be alternately removed from the electron beam in order to measure the "pure" RTXR and PXR.

The detector consisted of a NaI(Tl) γ-ray spectrometer with a 1-mm-thick crystal.

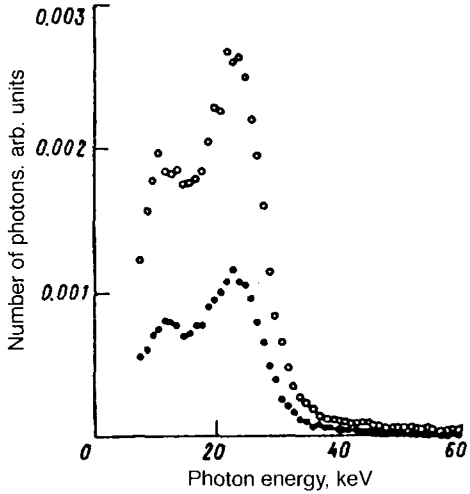

FIG. 2. Measured DTXR (●) and PXR (□) spectra.

The energy resolution was equal to 50% for ^{57}Co (14.6-keV line) and 25% for ^{241}Am (59.6- keV line). The detection threshold was set at 7 keV. The beryllium entrance window of the detector was 24 mm in diameter and 200 μm thick. To compare the characteristics of RTXR, PXR, and DTXR, the detector was placed in two positions: straight in the beam and at an angle $\theta_D = 18°12'$. The distance between the CT and the detector was equal to 458 cm in each case, and 243 cm of this gap consisted of air. The exit flanges of the vacuum chamber were made of 200-μm-thick beryllium.

Figure 2 shows the instrumental PXR and DTXR spectra. The first and second orders of these radiations can be seen in the figure. To measure these spectra, the upper detection threshold was set at about 40 keV. The amplitude of the first peak is lower than that of the second peak because of the stronger absorption in air. According to the figure, the DTXR spectrum is approximately 2.4 times more intense than the PXR spectrum.

We estimate the reflection linewidth as $\Delta E \simeq E_\gamma \cdot \Delta\theta \cot\theta_B$. It is well known[6] that for collimated PXR the parameter $\Delta\theta$ is determined by only two components: θ_{mos} — the mosaic structure of the crystal and θ_{ap} — the aperture of the detector. These same components also determine the DTXR linewidth. It can be asserted, therefore, that collimation of the x-ray beam, which involves placing a metal-foil target in front of the crystal, does not lead to appreciable broadening of the spectral lines of the x-ray source based on DTXR, while the the radiation intensity increases substantially.

For PXR we shall write the width of the angular distribution in the form

$$\Delta\theta^2 \sim \theta_{mos}^2 + \gamma^{-2} + (\hbar\omega_{pPG}/E_\gamma)^2 + \langle\theta\rangle_{ms}^2, \qquad (1)$$

where $\langle\theta_{ms}^2\rangle$ is the mean-square angle of multiple scattering of the electrons in the target material, and $\hbar\omega_{pPG} \simeq 31$ eV. For DTXR we have

$$\Delta\theta^2 \sim \theta_R^2 + \theta_{mos}^2 + \langle\theta\rangle_{ms}^2, \qquad (2)$$

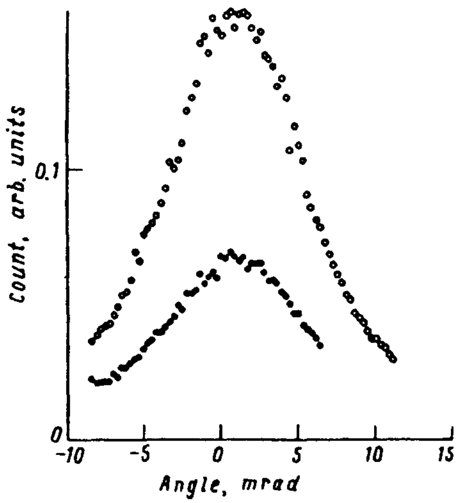

FIG. 3. Orientational dependences of DTXR (○) and PXR (●).

where

$$\theta_R^2=\frac{4\pi\hbar cr}{E_\gamma(l_1+l_2)}-\gamma^{-2}-\frac{l_2}{l_1+l_2}\left(\frac{\hbar\omega_{pCu}}{E_\gamma}\right)^2$$

is the squared radius of the ring distribution of the RTXR photons, l_1 and l_2 are respectively the spacing of the foils and the thickness of the foils in the multifoil target, r is the harmonic number, and $\hbar\omega_{pCu}\simeq 60$ eV. It should be noted that the parameters in expressions (1) and (2) determine the widths of the orientational dependences of PXR and DTXR.

In our experiment the largest quantity in expressions (1) and (2) is $\theta_{mos}\simeq 7$ mrad (Ref. 5) ($\gamma^{-1}=0.7$ mrad, $\langle\theta\rangle_{ms}\simeq 2.2$ mrad for the PG crystal and $\simeq 1.6$ mrad for the multifoil target, and θ_R is of the order of γ^{-1}). The same quantity — θ_{mos} — therefore determines the widths of the angular distributions of the PXR and DTXR. This should lead to the fact that, as noted above, the widths of the orientational dependences of DTXR and PXR should differ only slightly.

Figure 3 shows the measured orientational dependences of DTXR and PXR. In performing these measurements we recorded the number of photons in the range 7–30 keV as a function of the angle of rotation of the PG crystal around the vertical axis. According to the figure, at the maximum of the orientational dependence the DTXR intensity is 2.2 times higher than the PXR intensity, in agreement with the spectral measurements (see Fig. 2). The total width at half-maximum for the two orientational dependences is equal to ~10.5 mrad; i.e., we did not find any differences in the widths of the orientational dependences.

Figure 4 shows for comparison the measured RTXR, DTXR, and PRX spectra in the units photons/electron·keV. Since the RTXR spectrum is quite wide,^{2} the resolution of the detector does not significantly affect its shape. Curve 1 in Fig. 4 therefore shows the

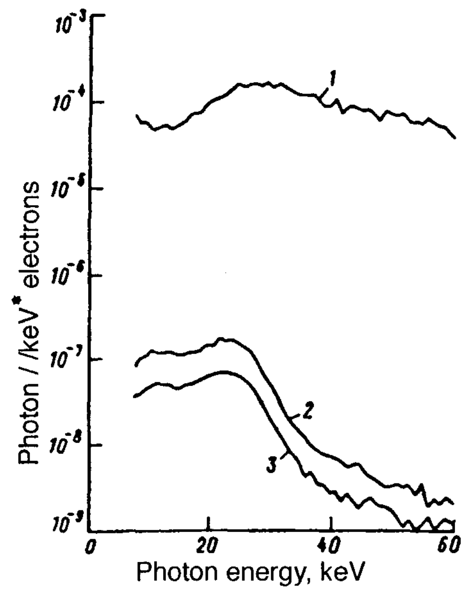

FIG. 4. Experimental RTXR (1), DTXR (2), and PXR (3) spectra.

dependence of the spectral density $\Delta N/\Delta\omega$ of RTXR as a function of the photon energy. The computed widths of the PXR and DTXR lines for the given values of θ_{mos} and θ_{ap} are $\Delta E \simeq 0.5$ and 1 keV for 11 and 22-keV photons, respectively. However, the resolution of the detector "smears" these lines in the measured spectra. To estimate the spectral densities of PXR and DTXR, we summed the number of photons in the experimental spectra in the ranges 7–16 and 18–27 keV and then normalized them to the expected spectral line widths. As a result, we found that the spectral density of the RTXR in the 11-keV line is approximately five times higher than the PXR spectral density and two times higher than the DTXR spectral density. For 22- keV photons this excess factor is 16 and 7, respectively.

Let us now we summarize the main results of this study.

1. Diffraction of transition radiation produced in a radiator consisting of copper foils on a pyrolytic graphite crystal was observed experimentally. The RTXR, DTXR, and PXR spectra were measured under identical experimental conditions and the spectra were compared with one another.

2. When a multifoil structure is placed in front of the crystal, the x-ray yield at large (Bragg) angles is substantially higher than in the case of "pure" PXR.

3. When mosaic crystals are used, the angular characteristics of the DTXR are virtually identical to those of PXR upon insertion of a multifoil target with a total thickness of 7.5×10^{-3} radiation lengths into the electron beam.

The DTXR source based on a compound target "multifoil structure + mosaic crystal" thus has virtually the same angular characteristics as the PXR source and its intensity is much higher.

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