METHOD OF STATE AND ALIGNMENT MONITORING FOR CRYSTAL DEFLECTORS OF RELATIVISTIC IONS*

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Abstract

The calculations of the parametric X-ray radiation (PXR) characteristics produced by 158 GeV/u Pb nuclei in silicon crystal deflectors were carried out. The PXR intensity at the maximum angular distribution was about 4 ph/Pb/sr, which should allow to monitor the state and the orientation of the deflector by means of the observation of the PXR spectrum characteristics.

INTRODUCTION

Systems of relativistic particle beam steering based on the use of channeling effect are widely applied in leading research centers of Russia and foreign countries. It was experimentally shown that with use of short crystals one can obtain extracted beams with intensity of ~ 10^{12} protons/cycle with efficiency of ~ 85% [1].

The radiation resistance of crystals is one of important characteristic in the applications of crystals for beam control of accelerator. Estimation of the limit value of the particle flux through the crystal before its destruction has been obtained in the experiments carried out at CERN (Switzerland) and BNL (USA) and is equal to ~ $2 \cdot 10^{20}$ protons/cm^2. Silicon crystals with efficiency $80 \div 85\%$ reliably provide the extraction up to 10^{12} particles per cycle duration of $1 \div 2$ seconds. When intensity of beam is about 10^{13} protons the crystal loses the capability to deflect the particles [2].

An operative control is required in the case of using crystal deflectors for the accelerator intensive beam collimation. The control should allow to conclude about the state and alignment of the crystal collimator relative to the beam halo.

In paper [3] we were proposed concept a method of exploiting parametric PXR as a monitor of deflector quality and orientation. PXR is emitted in directions satisfying the Bragg condition when relativistic charge particles are incident on a crystal and its properties strongly depend on kinematics of process [4-6]. Since its first observation [7] one studied using electron beams of different energies [8, 9]. The first experiment with the aim of PXR observation from heavy charged particles was carried out on the 70 GeV proton beam at IHEP [10]. After that PXR has been successfully observed from 5 GeV protons and 2.2 GeV/u carbon nuclei in a silicon crystal on the external beams of the Nuclotron at LHE JINR [11, 12]. Recently, PXR produced by 400 GeV/c protons in silicon deflector has been observed [13].

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The aim of this paper is to calculate the spectral and angular characteristics of the PXR from silicon deflectors when relativistic Pb nuclei are passing through them.

SIMULATION

The layout of numerical experiment is similar to work [13]. Fig. 1 shows the layout in the horizontal plane for the experiments with quasi-mosaic (QM) and strip (ST) silicon crystals. A beam of Pb nuclei with energy 158 GeV/u entered a crystal in the collimation geometry so that it is parallel to the deflecting planes, which are the (111) and (110) crystallographic planes for the QM and ST crystals, respectively.

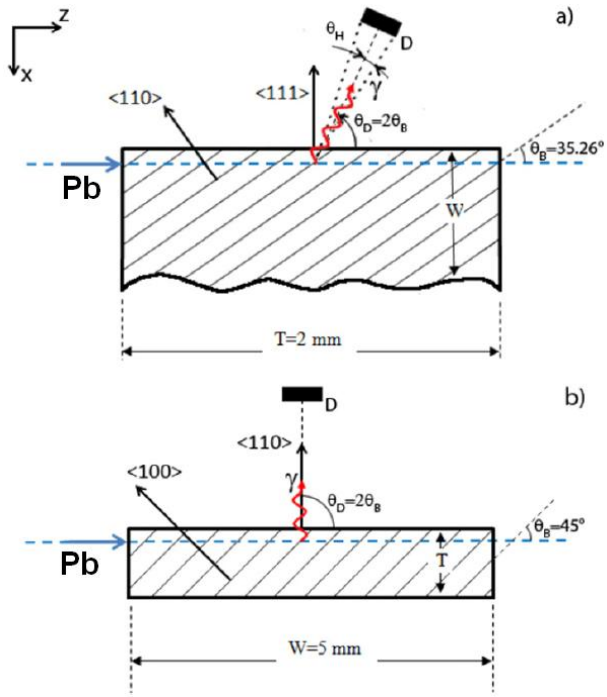

Figure 1: The simulation scheme details: (a) for quasi-mosaic crystal, (b) for strip crystal.

Simulation was carried out for a Gaussian incident beam with the cross-section σ = 1,0x0,7 mm^2 and σ = 10,7x7,8 μrad^2 divergence. A beam of Pb nuclei crossed the crystal with an offset of 0,7 mm depth in the QM case and in the centre in the ST case.

PXR is generated by particle field when it crossing a set of the crystallographic planes. PXR reflexes (110) and (100) in the case of (a) and (b) shown in Fig. 1, respectively, was calculated.

The energy of PXR photons is determined in the following way:

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$$E_n = n\frac{2\pi\hbar c}{d}\frac{\beta\sin\theta_B}{1-\beta\sqrt{\varepsilon}\cos\theta_D\cos\theta_y} \quad (1)$$

where n is the diffraction order, d is the interplanar distance, $\beta=v/c$ and ε is the dielectric constant of the target material ($\varepsilon = 1-(\omega_p/\omega)^2 \approx 1$, ω is the frequency of PXR photons, ω_p is the plasmon frequency), θ_B is the Bragg angle, θ_D and θ_y are the radiation registration angles. θ_D is the angle between the projection of the radiation direction and momentum in the diffraction plane. θ_y is the angle between projection of the radiation direction on the diffraction plane and the radiation direction. The diffraction plane is determined by the particle momentum and by vector normal to the crystal planes, its figure plane in Fig.1.

According to the formula (1) PXR photons energy of the reflex (110) for detection angle ($\theta_D=2\theta_B$) 70.52° is equal to 5.59 keV and to the reflex (100) for detection angle 90° is equal to 6,46 keV. The distance between the crystal and screen D was 117 and 200 mm in case QM and ST crystal, correspondently. The calculations of PXR characteristics have been performed according to the PXR kinematic theory [14], which describes well many experimental results. In the simulation a crystal considered as a set of the straight samples and PXR yield from all crystal can be presented as superposition of separate contributions from each sample. It should be noted that the PXR intensity must increase with the charge number Z of the particle as Z^2 therefore the PXR intensity from nuclei much more then from proton. The dependence on particle charge was experimentally observed in [11] with a large error.

Fig. 2 presents the simulation, the results of which show the difference between the intensities from Pb nuclei and protons. The intensities from Pb nuclei are more than from protons in 6724 times.

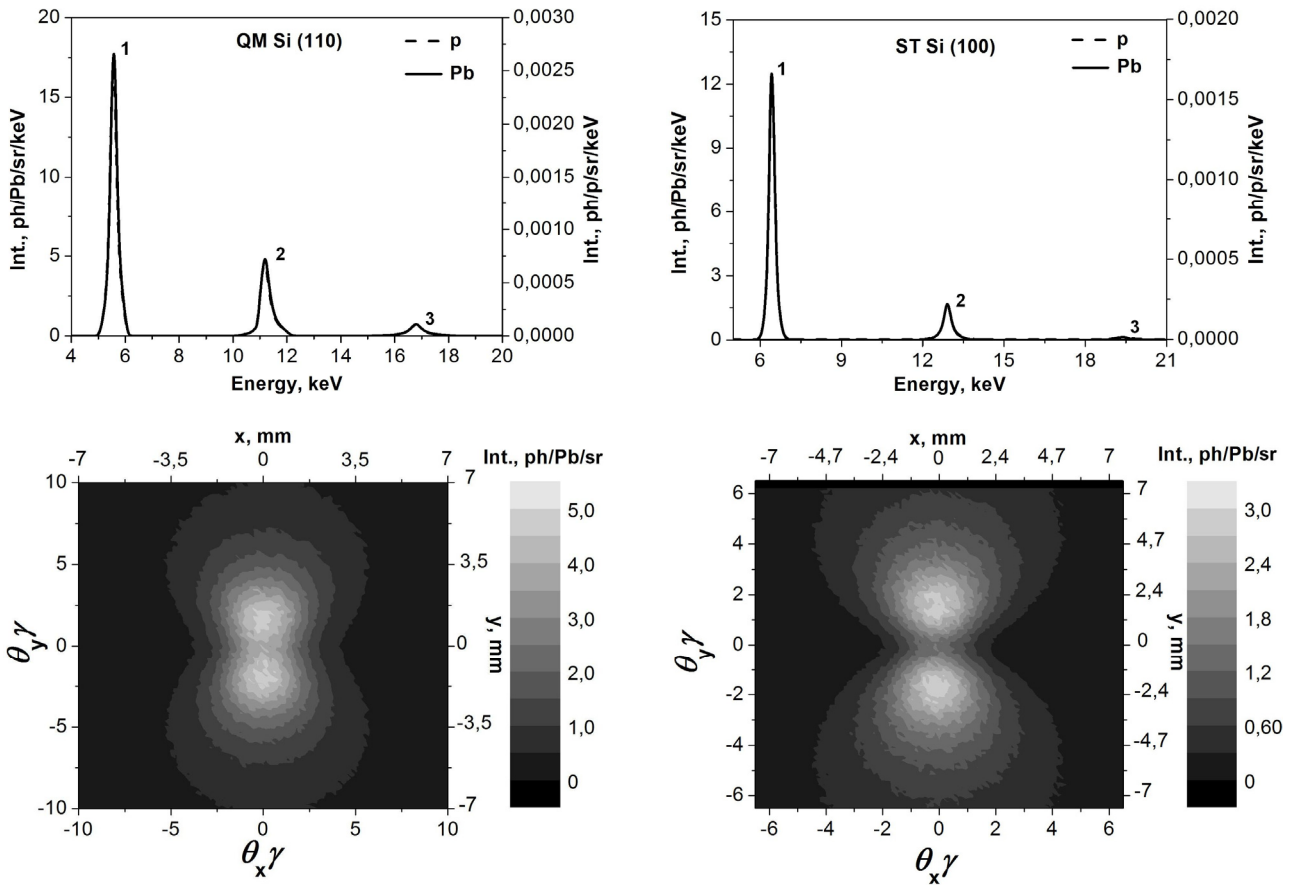

Figure 2: The spectra and angular distributions on the detector plane of the PXR from QM crystal (a) and ST crystal (b). Calculations were taking into account absorption in the crystal and the air.

CONCLUSION

The calculations of the spectral and angular characteristics of the PXR generated by Pb nuclei with an energy 158 GeV/u from planes (110) and (100) in the silicon deflectors were carried out. Expected values of the intensities are given in Table 1. As Table 1 shows intensity of PXR is about 2 ph/Pb/sr. Using a commercially available Si-PIN x-ray detector with a sensitive surface area about 10 mm^2 at a sufficiently distance from crystal about 100 cm the number of detected photons is equal to about 10^5 ph/cycle, which should allow to monitor the state and the orientation of

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the deflector by means of the observation of the PXR spectrum characteristics.

Table 1: Simulation result

Reflex	Energy of maximum, (keV)	Intensity I, ph/Pb/sr	**FWHM, eV**
(220)	5.59	2.998	259
(440)	11.19	1.375	330
(660)	16.79	0.009	432
(400)	6.46	2.241	182
(600)	12.91	0.522	296
(800)	19.39	0.061	407

REFERENCES

[1] Afonin A.G. et al., Proton beam extraction by a short silicon crystal from the IHEP accelerator, (IHEP Preprint: Protvino, 2003), 49.
[2] A.G. Afonin, et al., Phys. Rev. Lett. 87 (2001) p. 094802.
[3] Gogolev A.S. et al., NIMB 266 (2008) p. 3876.
[4] M.L. Ter-Mikaelian, High Energy Electromagnetic Processes in Condensed Media, (New York: Wiley - Intersci., 1972) 300.
[5] G.M. Garibyan, Yan Shi, Zh. Eksp. Teor. Fiz. 61 (1971) p. 930.
[6] V.G. Baryshevsky, I.D. Feranchuk, Zh. Eksp. Teor. Fiz. 61 (1971) p. 947.
[7] A.N. Didenko et al., Phys. Lett. A 110 (1985) p. 177.
[8] A.V. Shchagin, X.K. Maruyama, Accelerator-Based Atomic Physics: Technique and Applications, (New York: AIP Press, 1997), 279.
[9] P. Rullhusen, X. Artru, P. Dhez, Novel Radiation Sources Using Relativistic Electrons, (Singapore: World Sci., 1998) 370.
[10] V.P. Afanasenko et al., Phys. Lett. A 170 (1992) p. 315.
[11] Yu.N. Adishchev et al., JETP Lett. 81 (2005) p. 241.
[12] Yu.N. Adishchev et al., NIMB 252 (2006) p. 111.
[13] W. Scandale et al., Phys. Lett. B 701 (2011) p. 180.
[14] H. Nitta, Phys. Rev. B 45 (1992) p. 7621.

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