THE PROPOSAL OF THE EXPERIMENT ON THE RESEARCH OF THE DIFFRACTED CHANNELING RADIATION

D.A. Baklanov*[1]*, V.K. Grishin*[2]*, A.N. Ermakov*[2]*, R. A. Shatokhin*[1]*,
***I. E. Vnukov*[1]**, Yu.V. Zhandarmov*[1]**

[1] *Belgorod State University, 14 Studencheskaya str., 308007, Belgorod, Russia*

[2] *Research Institute of Nuclear Physics, MSU, Moscow, Russia*

(Received February 28, 2008)

The possibility of experimental detection of the diffracted channeling radiation with the energy $15 \ldots 40\,MeV$ for the conditions of the microtron of RINP, MSU. We propose a new way of orientation of the crystal according to the radiation yield under channeling on the electronic accelerators of the average energies with the short time of the acceleration cycle and dropping of the electrons to the target (microtron, linear accelerator) by the integral characteristics of the soft radiation yield from the thin metal targets. It provides the ten times reduction of time spending on the orientation. The main part of necessary experimental equipment is prepared and test measurements are taken.

PACS: 11.60-m, 61.85+p,78.70-g

1. INTRODUCTION

Diffracted channeling radiation (DCR) or, as it's sometimes called, diffracted radiation of relativist oscillator is one of the interesting physical phenomena, occurring when fast charged particles pass through clustered environments. They were forecast in the 70-80s in the works of Baryshevsky V.G. with coauthors. Some of them were registered experimentally, e.g. parametric X ray (PXR) of fast particles in crystals and PXR at small angles to the direction of the particle speed in crystals [1, 2]. DCR, which is a result of coherent combining of two processes - photon radiation and its diffraction in a crystal (see [3] and references therein), till recent years remained out of experimenters' attention because of some vagueness in the value of the effect and evident complexity of its separation from the competitive processes: PXR and diffracted bremsstrahlung (DB). The additional problem in conducting the researches on the revealing of this effect is the comparatively narrow range of particles energy where the clear display of the effect is possible ($7 \ldots 40\,MeV$) and very narrow range of photons energies where it can reveal. This makes rigid requirements to the choice of the observation angle and collimation of radiation [4].

Recently, after the cycle of works [4, 5, 6, 7], situation with the value of effect has become more clear. According to the results of the quoted works in the narrow angle range the DCR yield can be some orders larger than PXR yield. If this value is true it is possible to create a new intensive tunable X-ray source, because from the practical point of view the radiation source based on the PXR mechanism is not profitable [8]. The authors' idea [3] about the possibility of interference of radiation mechanisms when channeling and PXR also seems to be rather interesting. In this case, fulfilling the conditions of diffraction for photons, emitted during the electron passing from one state to another, we can expect the change of the correlation of peaks in the spectrum of the channeling radiation. As the interference of coherent bremsstrahlung and channeling radiation was observed experimentally [9, 10] the registration of the effect of the interference of radiation mechanisms during channeling and PXR is an interesting physical task. Reasoning from the premises the experimental researches aimed at verification of theoretical forecasts about the value and characteristics of DCR are undoubtedly important and actual.

2. EXPERIMENTAL SETUP AND METHOD

From the methodical point of view the most attractive is a range of photons energies $20 \ldots 35\,keV$. It can be realized on the accelerators with energy $20 \ldots 30\,MeV$. Because of the low absorption of photons of these energies in the air the experiment can be conducted without degassing of photon trace, and the detector can be carried on the large distance from the accelerator to decrease the background. The experiment should be carried out on the split microtron (Research Institute of Nuclear

---

*Corresponding author. E-mail address: vnukov@bsu.edu.ru

Physics, Moscow State University) [11] with the current $\sim 3\,mA$ ($\sim 10^{12}$ particles for the cycle of acceleration), the frequency $10\,c^{-1}$ and the duration of the radiation cycle $\tau \sim 8\ldots 10\,\mu c$. The derived electron beam, the demanded energy range $(15\ldots 65\,MeV)$ and the possibility to change the particles energy permit to hope for the successful separation of this type of radiation from PXR and DB background.

The scheme of the experiment is given on Fig.1. Electrons from 5 or 6 orbit of the microtron ($E_e = 25.2\,MeV$ or $30\,MeV$) are taken out to the jet chamber, where there is a triaxial goniometer with the crystal set on it and there are some windows for letting the radiation out. The working range of the rotation angles of the crystal around the horizontal and vertical axes Θ_v and Θ_h – ±5° with the rotation step 0.01°. The range of the rotation angles around the axis of electron beam $\varphi - \pm 5°$ with the step 0.04°.

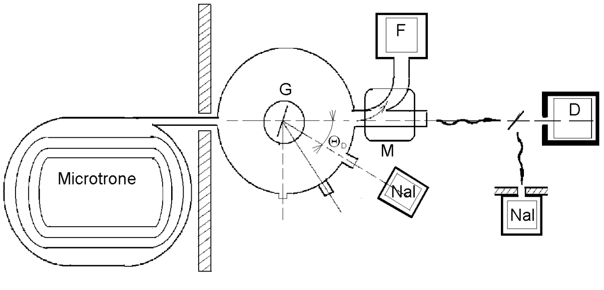

Fig.1. *Experimental setup*

The extracted electron beam will be measured by the drag-type sensor during the high current or by the monitor of the second emission in the regime of the spectral measurements. Interacted electrons are turned aside to the beam-gap with the bending magnet (M). There also the faraday cylinder (F) for the calibration of the sensor of second remission can be installed. The main problem to solve is that till recent time the accelerator has been used to conduct the researches of the sections of nuclear reactions where dosimeter (D) is enough and there is no need in exact measuring of the current in every cycle of acceleration and there are no sensors for measuring small currents. This part of the plant is now being worked out and partly tuned.

From the conditions of the simplicity of the experiment the channeling plane should coincide with the horizontal plane and the plane where the radiation diffractions occur under the channeling is unfolded at the demanded angle $\Theta = \Theta_D/2$. To register the required radiation it is proposed to use the X-ray NaI detectors (as it can be seen from the practice for the photons energies more than $20\,keV$ their resolution is enough to pick out PXR from the steady background) or silicon pin-detectors.

For certain marking of the required effect the measurements of angle distribution of the X-ray yield should be conducted. The angle distribution of DCR should be narrower than PXR distribution. The control test will be the same measuring of other electrons energies. All conditions for PXR and DB will be saved almost entirely but the there won't be coincidence of radiation energy and diffracted photons necessary for the realization of the required effect during channeling.

To observe the effect it is necessary to orient the crystal plane along the electron beam, i.e. to go out to the channeling regime. Here the main problem is that the methods of crystal orientation by radiation yield during channeling (with the help of the collision chamber [12] or NaI (Tl) detector in Compton geometry [13]), which are usually used on the accelerators of higher energies, are not suitable for the electrons with the energy of several tens MeV because typical radiation energy during channeling is not more than $50\ldots 100\,keV$. Besides the correlation of the intensities of coherent and deceleration components of radiation decreases with the diminution of particles energy.

Using of spectrometric regime of detector working for the crystal orientation is not suitable first of all because of the economical reasons. Requiring the absence of impositions (the number of detector's abrasions is not more than $0.3\ldots 0.4$ for the acceleration cycle) for the registration of the spectrum with sufficient statistics ($\sim 10^3$ events) at least 5 minutes are required. I.e. to measure one orientational dependence $\sim$ 200 points about 10 hours are needed and the process of orientation demands usually more than one measurement. It should be noted that the necessary for the regulation of the registered spectrums measurement of such small currents ($\sim 10^2 - 10^3$ particles during acceleration cycle) is a difficult technical task.

That is why for the orientation of the crystal we propose to use the X-ray NaI detector with the thickness $1\,mm$, located at the angle 90° which registers the increase of the characteristic X-ray yield (CXR) out of the thin metal target, installed on γ-beam fulfilling the channeling conditions. Such method of orientation in the counting regime was already used in the conditions of accelerating hall of Tomsk's synchrotron for the electrons energies $500\,MeV$ and it showed good sensitivity [14]. By the exchange of this scatterer we can obtain the optimal correlation signal/background for the chosen plane, on which the channeling takes place (see the next part). Measurements should be conducted in the current regime of the detector's switching on. The charge, cumulative during the one cycle of acceleration, is digitized by ADC. The detector of bigger volume with the same connection will be used to measure the intensity of the background bremsstrahlung, proportionate to the number of the accelerated electrons. This permits to work in the usual regime for the accelerator and almost in order decrease the time of the crystal orientation.

Test measurements of the scattered radiation yield confirmed the possibility of the separation of the useful effect from the hall background. The correlation of the detector's response with the target on the drag beam wasn't worse than 2-3 even without it. The spectral measurements with the lead target confirmed the predominant input of CXR photons in the yield of the registered radiation.

3. SIMULATION

To check the application of the proposed method of crystal orientation for the lesser electrons energies than in the experiment [14] we held the simulation of the dependencies of the integral response of the detector, i.e. the energy absorbed in the detector, on the spectrum of the analyzed radiation, material and the thickness of the target. The photon beam falls on the target set at the angle 45°. The scattered radiation is registered by the NaI (Tl) detector with the thickness $1\,mm$, set at the angle 90° on the 1 meter distance from the target. The collimation angle of the scattered radiation is 2°. The calculations showed that the main input in the yield of the registered radiation is given by the photoeffect of the photons of the first beam in the target. The input of the scattered Compton photons for all targets wasn't more than a fraction of a percent. This is caused both by the small value of the section and low effectiveness of the counter for photons energies $\omega > 100\,keV$.

In the process of simulation we considered the absorption of the first and scattered radiation in the material of the target and in the air on the way from the target to the detector and the effectiveness of the detector. The bremsstrahlung of the second particles wasn't considered because of the small thickness of the target. To compare we used the results of the experiment [15] on the research of the radiation with plane (110) channeling of the electrons energy of $30\,MeV$ in the silicon crystal with the thickness $15\,\mu m$. On Figure 2 there are the initial sectors of the radiation spectra, used in simulation.

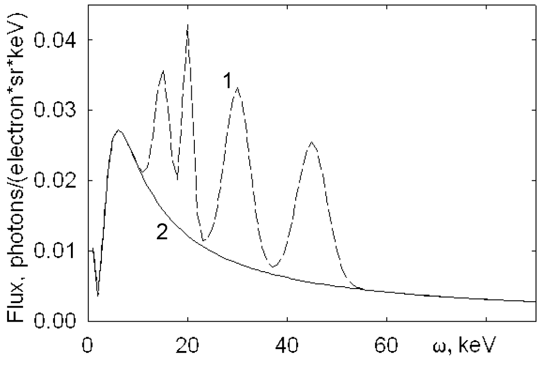

Fig.2. *The emission spectra of electrons energy of 30 MeV in the silicon crystal thickness of 15 μm for the condition of Ref.[15]*

The model radiation spectrum during channeling (Curve 1) renders the experimental spectrum [15] with the error not more than 30%, it more likely understates the channeling radiation yield than gives it too high. The bremsstrahlung spectrum (Curve 2) is calculated from the spectral-angle Schiff's distribution [16] taking into account the parameters of the given experiment: the initial divergence of the photons beam, multiply scattering of the particles in the crystal and photons absorption. The full number of photons in the spectrum of channeling radiation is about 25...30% higher than in the spectrum of the bremsstrahlung from the disoriented crystal.

The calculation is fulfilled for the targets of lead, tin, silver, molybdenum, niobium and copper, i.e. for such wide-spread materials of which thin foils can be made.

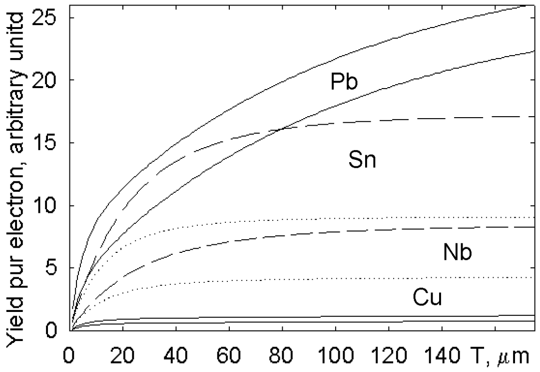

Fig.3. *The dependence of the detector response from the emission spectra hitting on the target, its material and thickness*

On Figure 3 there is the dependence of the detector's response on the target thickness for several materials and different radiation spectra. As it can be seen from the figure the substances with large Z provide larger response because of the larger CXR photons energy. At the same time the difference of the response value for the spectrums of channeling radiation and bremsstrahlung, which is the most important from the point of view of application of the developed method of the crystal orientation, is maximum for the substances with average Z (tin, silver, see Fig.4).

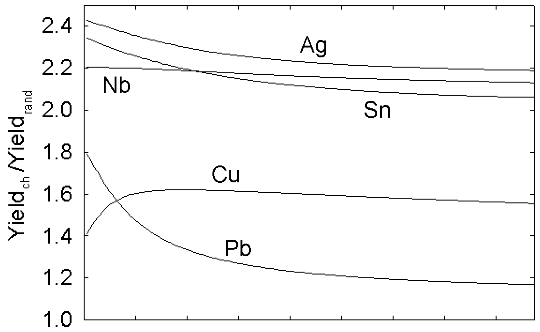

Fig.4. *The dependence of the detector response correlation for emission with different spectra from the target material and thickness*

It should be noted that the registered radiation yield practically comes out to saturation for the target thicknesses $40\ldots70\,\mu m$, that is caused by the large section of the photoabsorption in the area of the energies. That is why the optimal thickness of the target shouldn't exceed $50 \dots 100\,\mu$. The further increase of the target thickness will lead to the increase of the input of the bremsstrahlung of second particles. On Fig.4 there is a dependence of the correlation of registered radiation spectrum yield for the spectra of the channeling radiation and bremsstrahlung for the targets of lead, tin, silver, niobium and copper. It is seen from the figure that the best targets to realize the proposed method of the crystals orientation by the integral yield of the scattered radiation are silver and tin. Copper and lead lose because of the lesser value of the excess and small value of response (copper). It should be noted that for the targets with optimal thickness the correlation of the registered yields of scattered radiation for the oriented and off-oriented crystals ($\sim 2.4 \dots 1.5$)is rather better than the correlation of the photons number in these spectrums ~ 1.3. So the proposed method of orientation really works in the accelerator with the short time of acceleration and gives the opportunity to reduce the time of crystal orientation.

Rather high sensitivity of the proposed method and the threshold character of the dependence of the photoabsorption section on the photons energy permits to test the interference of the PXR mechanisms and channeling radiation in the case of fulfilling the diffraction conditions for the photons of one or another peaks in the radiation spectrum during channeling (see the introduction and [3]) without laborious spectral measurements. We take the silicon crystal with the orientation <111>, and the plane (110) coincides with the horizontal, and (112) with vertical and electrons energy $30\,MeV$. In compliance with the results of the experiment [15] (see Fig.2) in the radiation spectrum with plane (110) channeling of the electrons with the energy $30\,MeV$ in the silicon we can observe 4 clear peaks with energies 45, 29.2, 19.7 and $13.6\,keV$.

For the orientation <111> and the chosen geometry the strongest reflection should be observed on the plane (112) (reflection (224)) and 2 planes of the type (110) (reflection (220)), unfolded relative to vertical plane at the angles ±30°, see e.g. [2]. If the required effect exists then in the radiation spectrums during the plane channeling the peculiarities for the angles of off-orientation of the crystal axis $\Theta = 82.9$ and $124.6\,mrad$ ($\omega = 45\,keV$), $\Theta = 127.9$ and $192.2\,mrad$ ($\omega = 29.2\,keV$), $\Theta = 192$ and $287.8\,mrad$ ($\omega = 19.7\,keV$), $\Theta = 277$ and $424.6\,mrad$ ($\omega = 13.6\,keV$) should be observed. The first value of the angle of off-orientation corresponds to the Bragg's condition for the photons of these energies on the planes (110), and the second - on the plane (112). In other words while measuring the oriented dependence of the scattered radiation yield for these angles of the axis off-orientation the yield of the registered radiation should change.

The threshold of the absorption on K shell for tin is $29.2\,keV$, for silver – $25.51\,keV$, for niobium – $18.99\,keV$, for copper – $8.98\,keV$. That is why during the measuring of the oriented dependencies using the thin foils of these materials the spectrum change caused by the fulfilling of the diffraction condition will reveal not equally. E.g. thin target of niobium should be more sensitive to the change of peak intensity with $\omega = 19.7\,keV$ for the angles of orientation $\Theta = 190 \dots 300\,mrad$, while for the tin targets the change of this peak intensity won't influence on the registered radiation yield.

With the increase of the crystal thickness the correlation of the intensities of coherent and incoherent components decreases. Nevertheless for the crystal thickness $0.2\,mm$ the correlation of the registered radiation yield for the spectrum of channeling radiation and bremsstrahlung remains 1.1 or 1.2, that let us hope for successful registration of the required effect for the larger thicknesses of the crystal.

4. CONCLUSION

The necessary minimum of the required equipment and conducted evaluations allow hoping for the successful fulfilling of the proposed researches. At the first stage we will finally test the proposed method of the crystal orientation by the scattered radiation yield and search the influence of the diffraction conditions on the radiation yield during channeling. The work is fulfilled with partial support of RFBR (grants 05-02-17648 and 08-02-00816a) and the programme of inner grants of BelSU.

References

1. S.A. Vorobiev, B.N. Kalinin, S. Pak, A.P. Potylitsyn. Observation of monochromatic X-ray emission with passing of ultrarelativistic electrons through diamond// *JETP Lett.* 1985, v.41, p.1-4.

2. A.N. Aleinik, A.N. Baldin, E.A. Bogomazova, I.E. Vnukov, B.N. Kalinin, A.S. Kubankin, N.N. Nasonov, G.A. Naumenko, A.P. Potylitsyn, A.F. Sharafutdinov. Experimental observation of prarmetric X-ray radiation directed along the propagation velocity of relativistic electrons in a tungsten crystal // *JETP Lett.* 2004, v.80, N3, p.393-397.

3. V.G. Baryshevskii, I.Ya. Duboskaia. Diffraction phenomena in spontanious and collective emission of relativistic electrons in crystals // *Itogi Nauki Tekh. Ser.: Puchki Zariazhen. Chastits Tverd. Telo.* M: VINITI, 1991, v.4, p.129-225 (in Russian).

4. O.V. Bogdanov, K.B. Korotchenko, Yu.L. Pivovarov. Angular distribution of diffracted X-ray radiation under (111) electron channeling in Si: influence of zone structure of energetic levels// *Pis'ma v JETP.* 2007, v.85, p.684-688 (in Russian).

5. T. Ikeda, Y. Matsuda, H. Nitta and Y.H. Ohtsuki. Parametric X-ray radiation by relativistic channeled particles// *Nucl. Instrum. and Meth. in Phys. Res.* 1996, B115, p.380-383.

6. Y. Matsuda, T. Ikeda, H. Nitta and Y.H. Ohtsuki. Numerical calculation of parametric X-ray radiation by relativistic electrons channeled in a Si crystal// *Nucl. Instrum. and Meth. in Phys. Res.* 1996, B115, p.396-400.

7. R. Yabuki, H. Nitta, T. Ikeda and Y.H. Ohtsuki. Theory of diffracted channeling radiation// *Phys. Rev.* 2001, B63, 174112.

8. A.N. Baldin, I.E. Vnukov, R.A. Shatokhin. Using mosaic crystals for the generaion of intense X-ray beam// *Technical Psysics Letters.* 2007, v.33, p.625-628.

9. J.U. Andersen and E. Laesgaard. Coherent bremsstrahlung and sidebands for channeled electrons// *Nucl. Instrum. and Meth. in Phys. Res.* 1988, B33, p.11-17.

10. C.Yu. Amosov, I.E. Vnukov, B.N. Kalinin, et. al. Influence of channeling effect of ultrarelativistic electrons on type B coherent bremsstrahlung spectrum // *Pis'ma v JETP.* 1992, v.55, p.587-590 (in Russian).

11. V.I. Shvedunov, A.N. Ermakov, A.I. Karev, E.A. Knapp, N.P. Sobenin and W.P. Trower // *Proceedings of the 2001 Particle Accelerator Conference.* Chicago, p.2596.

12. D. Lackey , R.F. Scwitters. Methods of crystal alignment for the production of coherent bremsstrahlung//*Nucl. Instrum. and Meth.* 1970, v.81, p.164-172.

13. B.N.Kalinin, E.I.Konovalova, G.A.Pleshkov, A.P.Potylitsin, V.M.Tarasov, V.K.Tomchakov, and I. Khakberdiev. Automatic orientation system for single crystal target in an electron accelerator// *Instrum. and Exp. Tech.* 1985, v.28, N3. p.533-535.

14. A.N. Baldin, I.E. Vnukov, D.A. Nechaenko, R.A. Shatokhin. Influence of crystals mosaicity on charakteristics of parametric X-ray radiation// *The Journals of Kharkiv National University. Physical series "Nuclei, Particles, Fields".* 2007, v.744, N3(31), p.51-65 (in Russian).

15. C.K. Gary, A.S. Fisher, R.H. Pantell, J. Harries, M.A. Piestrup. Channeling of electrons in Si produces intense quasimonocromatic, tunable, picosecond x-ray bursts// *Phys. Rev.* 1990, B42, p.7-14.

16. L.I. Schiff. Energy - angle distribution of thin target bremsstrahlung //*Phys. Rev.* 1951, v.83, p.252-257.

ПРЕДЛОЖЕНИЕ ЭКСПЕРИМЕНТА ПО ПОИСКУ И ИССЛЕДОВАНИЮ ДИФРАГИРОВАННОГО ИЗЛУЧЕНИЯ КАНАЛИРОВАННЫХ ЭЛЕКТРОНОВ

Д.А. Бакланов, В.К. Гришин, А.Н. Ермаков, Р.А. Шатохин, И.Е. Внуков, Ю.В. Жандармов

Обсуждается возможность экспериментального обнаружения дифрагированного излучения каналированных электронов с энергией 15 ... 40 МэВ для условий микротрона НИИ ЯФ МГУ. Предложен новый способ ориентации кристалла по выходу излучения при каналировании на электронных ускорителях средних энергий с коротким временем цикла ускорения и сброса электронов на мишень (микротрон, линейный ускоритель) по интегральным характеристикам выхода мягкого излучения из тонких металлических мишеней, обеспечивающий существенное уменьшение временных затрат на ориентацию по сравнению с известными. Подготовлена основная часть необходимого экспериментального оборудования и выполнены тестовые измерения.

ПРОПОЗИЦІЯ ЕКСПЕРИМЕНТА ДЛЯ ПОШУКУ ТА ДОСЛІДЖЕННЯ ДИФРАГОВАНОГО ВИПРОМІНЮВАННЯ КАНАЛЮЮЧИХ ЕЛЕКТРОНІВ

Д.А. Бакланов, В.К. Гришин, А.Н. Єрмаков, Р.А. Шатохін, І.Є. Внуков, Ю.В. Жандармов

Розглядається можливість експериментального спостереження дифрагованого випромінювання каналюючих електронів з енергією 15 ... 40 МеВ в умовах мікротрона НДІ ЯФ МДУ. Запропоновано новий спосіб орієнтування кристалу по виходу випромінювання при каналюванні на електронних прискорювачах середніх енергій з коротким часом циклу прискорення та скидання електронів на мішень (мікротрон, лінійний прискорювач) по інтегральним характеристикам виходу м'якого випромінювання із тонких металічних мішеней, забезпечуючий суттєве зменшення часових затрат на орієнтування порівняно з відомими. Підготовлена основна частина необхідного експериментального обладнання та виконані тестові вимірювання.