MONOCHROMATICITY OF GRATING TRANSITION RADIATION

A. Aryshev[A,B], S.Araki[A], K.Artyumov[C,G], M.Fukuda[A,B], Y. Morikawa[A], R. Morita[D], A.Kotlyarov[C], G. Naumenko[C], A. Potylitsyn[C], D.Yu. Sergeeva[E], M. Shevelev[C], D.Shkitov[C], L. Sukhih[C], Y-I. Tadenuma[D], T. Tanba[D], N. Terunuma[A,B], A.A. Tishchenko[E,F], J. Urakawa[C], M. Washio[D]

[A)]KEK: High Energy Accelerator Research Organization, Tsukuba, Ibaraki, Japan
[B)]SOKENDAI: The Graduate University for Advanced Studies, Tsukuba, Ibaraki, Japan
[C)]Tomsk Polytechnic University, Tomsk, Russia
[D)]Research Institute for Science and Engineering, Waseda University, Tokyo, Japan
[E)]National Research Nuclear University (MEPhI), Moscow, Russia
[F)]National Research Centre “Kurchatov Institute”, Moscow, Russia
[G)]Institute of High Current Electronics SB RAS, Tomsk, Russia

Abstract

A strong interest for developing of intense monochromatic THz radiation sources is explained by its unique features, such as non-ionizing interaction with matter, weak absorption in dielectrics, etc. The KEK: LUCX facility can produce THz/subTHz radiation via coherent transition/diffraction radiation (CTR/CDR) mechanisms as the rms electron bunch length is of the order of 0.15 mm. Spectral characteristics of CTR when the electron beam interacts with a grating instead of a flat metal foil usual for conventional CTR were studied and CTR continuous spectral distribution transformation into discrete spectral lines (so-called Grating Transition Radiation, GTR [1]) was confirmed. Moreover, GTR spectral line splitting for orientation angles much larger than the inverse Lorentz factor was observed. In this report, spectra measurement results and its comparison with Smith-Purcell radiation is presented and further developments are discussed.

INTRODUCTION

Electromagnetic radiation in the terahertz (THz) range attract attention due to its potential application in a different applied fields: biology, medicine, cargo inspection, etc. Many of existing THz sources based on the compact linear accelerators [1, 2] employ the coherent transition radiation mechanism to generate broadband emission spectrum. However, large number of applied investigations require monochromatic sources and additional devices for radiation monochromatization are currently considered. In our previous experiment [3] we have showed that the short electron bunch passing through a grating instead a conventional foil generates radiation, spectrum of which consists of the narrow-band spectral lines (so-called grating transition radiation, GTR).

The dispersion relation which sets the connection between wavelength of the GTR spectral lines, observation angle θ and grating inclination (with respect to an electron beam) angle η has the following form:

$$\lambda_k = \frac{d}{k}\left(\frac{\cos\theta}{\beta} - \cos\left(\eta-\theta\right)\right), \quad \nu_k = \frac{c}{\lambda_k} \tag{1}$$

Here k is the diffraction order, d is the grating period, $\beta = v/c$. Evidently, for the grating orientation $\theta = 0$ the relation Eq. (1) reduces to the well-known Smith-Purcell formula. We have investigated a monochromaticity of the Smith-Purcell radiation (SPR) before [4] and in this report, we have compared it with the GTR monochromaticity.

RESULT OF SIMULATIONS

The generalized surface current method [5] to simulate GTR characteristics for conditions of the LUCX facility was used. The GTR spectral-angular distribution is calculated from the field strength obtained by integration over a grating surface:

$$\frac{d^2W}{d\omega d\Omega} = cr^2\left|E_R^D\left(r_D,\lambda\right)\right|^2 \tag{2}$$

$$E_R^D\left(r_D,\lambda\right) = \frac{1}{2\pi}\int\int\left[\left[n\left(r_T\right), E_R^T\left(r_T,\lambda\right)\right], \nabla G\left(r_T, r_D, \lambda\right)\right] dS_T \tag{3}$$

For calculations of the integral $\int\int dS_T$ in Eq. (3) the real grating surface (see Fig. 1) for which we found a sum of integrals over surface of each period was taken. As it was shown in the paper [5] the Green function can be presented as following:

$$\nabla G\left(r_T, r_D, \lambda\right) = \frac{r_D - r_T}{\left|r_D - r_T\right|^2} e^{ik\left(r_D - r_T\right)}\left(\frac{1}{\left|r_D - r_T\right|} - ik\right),$$

and the normal to the grating surface in Eq. (3) was calculated for each period as $n\left(r_T\right) = A\left(\psi\right)\{0,0,1\}$, where $A\left(\psi\right)$ is the rotation matrix for the angle ψ (see Fig. 1). Grating parameters are presented in Table 1.

The field of the initial electron is given by the following expression:

$$E_e^T(r_T,\lambda)=\frac{2qe^{i\frac{k}{\beta}z_T}}{\beta^2 c\gamma\lambda}\left\{\begin{array}{c}\frac{x}{\sqrt{x_T^2+y_T^2}}\times\\ K_1\left(\frac{k}{\beta\gamma}\sqrt{x_T^2+y_T^2}\right)\\ \frac{y}{\sqrt{x_T^2+y_T^2}}\times\\ K_1\left(\frac{k}{\beta\gamma}\sqrt{x_T^2+y_T^2}\right)\\ -\frac{i}{\gamma}K_0\left(\frac{k}{\beta\gamma}\sqrt{x_T^2+y_T^2}\right)\end{array}\right\} \tag{4}$$

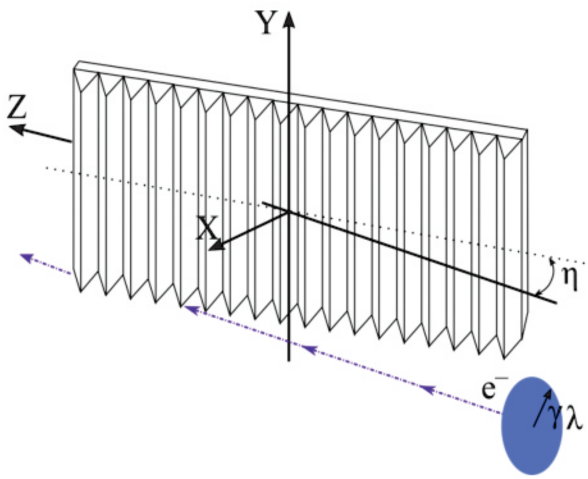

Figure 1: Geometry of experiment. Here η – grating tilt angle; λ - radiation wavelength; γ – Lorenz-factor.

Table 1: Grating Parameters

Material	Al
Period numbers	15
Period (AC)	4 mm
Full length	59.46 mm
Width	30 mm
Strip dimensions	3.46 (BC)×30 mm^2
Strip tilting angle (φ)	30°
Target height (BD)	1.73 mm
AB and DC	2 mm and 3 mm

Further we calculate the horizontal polarization component (HP) of the field E_R^D, because the vertical component is equal to zero since the electron beam passes through a grating center.

Figure 2*a-c* shows simulation results obtained for the grating under consideration, electron beam energy 8 MeV and the observation angle $\eta = 90°$. As one can see, for a small inclination angle $\theta = 5°$ there is a tendency for spectral line splitting only for a low diffraction orders. For inclination angles $\theta \gtrsim \gamma^{-1}$ such a splitting effect becomes sharper.

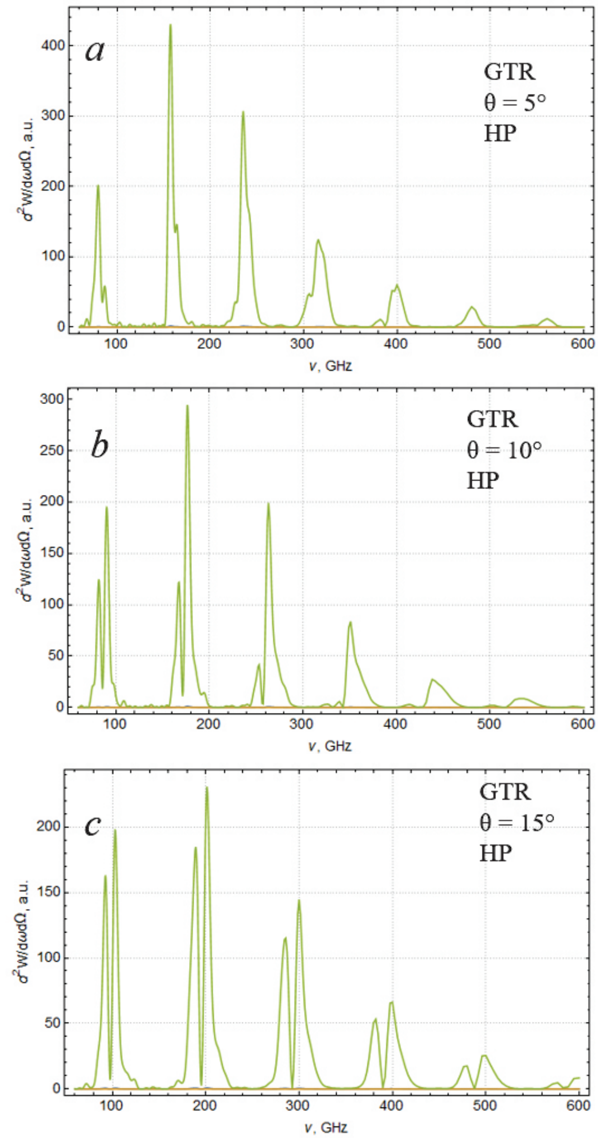

Figure 2: GTR spectra for different grating inclination angles.

It should be noted that the dispersion relation (1) gives a value ν_k corresponding to a minimum between split peaks. Despite such a splitting, widths of the spectral lines remain small enough for a large inclination angles. As an example, characteristics of spectral lines for the angle $\theta = 15°$ are presented in Table 2.

EXPERIMENTAL RESULTS

Experimental layout is shown in Fig. 3. Its detailed description can be found in [4]. KEK LUCX beam parameters are presented in the inset of the figure. We investigated GTR spectral characteristics using Michelson interferometer [6] and Schottky barrier diodes (SBD) with spectral sensitivity ranges 60 – 90 GHz and 140 – 220 GHz. Pre-

Table 2: GTR Spectra Lines Parameters

Diffraction order, k	**1**	**2**	**3**	**4**
ν_k, GHz	98	197	295	394
$\Delta\nu_{spl}$, GHz	10.6	12.1	15.1	18.1
$\Delta\nu\ (FWHM)$, GHz	19	23	28	37
$\Delta\nu/\nu_k$	0.19	0.12	0.10	0.09

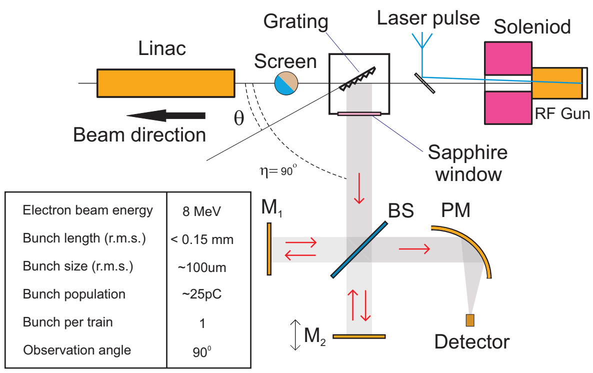

Figure 3: Experimental set-up.

liminary adjustment of the grating with respect to electron beam was performed by measuring bremsstrahlung yield along electron beam direction and after that, "zeroth" target orientation was determined by backward transition radiation scan (see, Fig. 4). The reconstruction procedure of the GTR

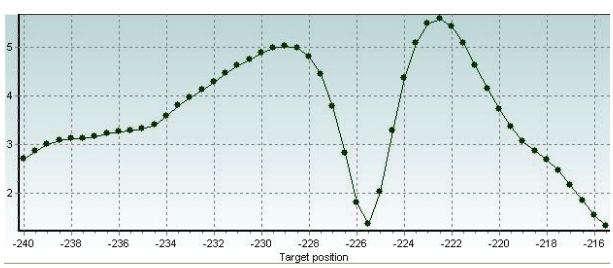

Figure 4: Dependence of the CTR yield on the target rotation angle.

spectra was conducted in analogy with Smith-Purcell radiation reconstruction described in [4]. Typical GTR spectra are presented in Fig. 5 and Fig. 6. One can see that there is a clear evidence of the spectral line splitting.

DISCUSSION

We have observed GTR lines with no splitting for a small inclination angles in agreement with simulations performed for the same experimental geometry and beam parameters. For $\theta \sim \gamma^{-1}$ angles, experimental spectral lines demonstrate just a "weak" dip between peaks in a contrast with the simulation results, where one can see almost complete separations between peaks (see, Fig. 2*c*). We suppose that this fact can be explained by a finite aperture of the interferometer system and imperfections of the Si splitter used in the interferometer and off-axis parabolic mirror as well as limited SBD aperture. Despite such a splitting effect, the spectral lines widths remains small enough and GTR can still be considered as potentially monochromatic source allowing for a fine spectral lines frequency tuning by the grating rotation for the fixed direction of the emitted radiation.

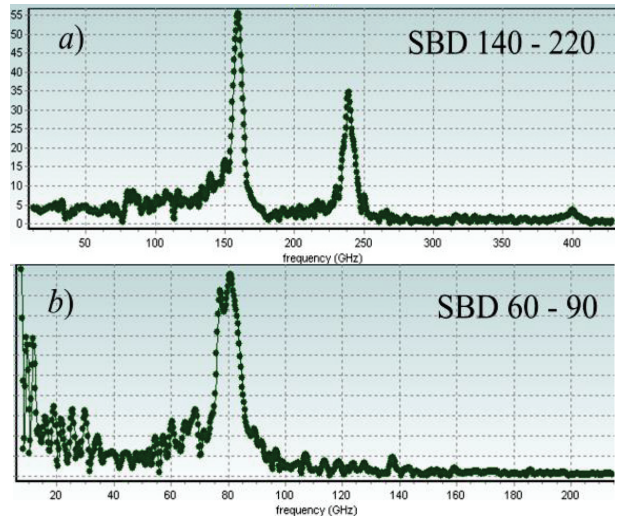

Figure 5: GTR spectral lines measured for grating inclination angles *a*: $\theta = 5°$ and *b*: $\theta = 7.2°$.

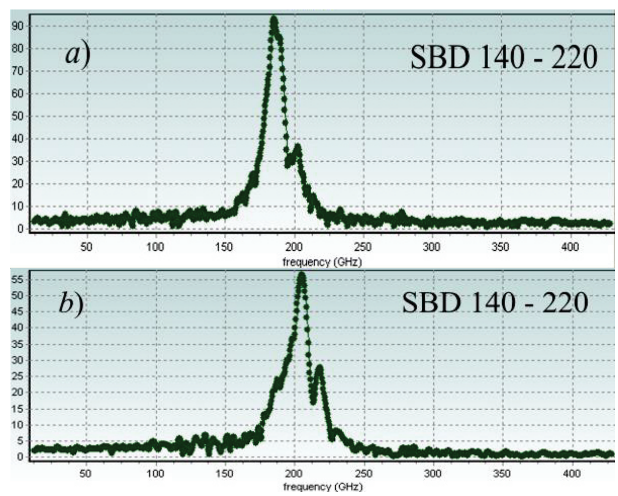

Figure 6: GTR spectral lines measured for grating inclination angles *a*: $\theta = 13.5°$ and *b*: $\theta = 17.5°$.

ACKNOWLEDGMENTS

The work was supported by the JSPS and RFBR under the Japan-Russia Research Cooperative Program (18-52-50002 YaF_a), the Competitiveness enhancement program of Tomsk Polytechnic University and the Competitiveness program of National Research Nuclear University "MEPhI".

REFERENCES

[1] S. Casalbuoni, B. Schmidt, P. Schmuser *et al*., Phys.Rev. ST-AB, 12, 030705 (2009).

[2] J. Park, C. Kim, J. Lee, C. Yim *et al*., Rev.Sci.Instr, 82, 013305 (2011).

[3] G. Naumenko, A. Aryshev, A. Potylitsyn *et al*., Nucl,Inst.Meth.Phys.Res. B, 402, 153 (2017).

[4] A. Aryshev, A. Potylitsyn, G. Naumenko *et al*., Phys. Rev. Accel. Beams 20, 024701 (2017).

[5] D. V. Karlovets and A. P. Potylitsyn, Phys. Lett. A 373, 1988 (2009).

[6] M. Shevelev, A. Aryshev, S. Araki *et al*., Nucl,Inst.Meth.Phys.Res. A, 771, 126 (2015).