EXPERIMENTAL INVESTIGATION OF THz SMITH-PURCELL RADIATION FROM COMPOSITE CORRUGATED CAPILLARY

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Abstract

We report experimental investigation of THz Smith-Purcell radiation (SPR) generated from corrugated capillary with reflector, using femtosecond electron beam of LUCX accelerator at KEK. Distribution of SPR was measured using narrowband Schottky Barrier Diode SBD and compared with Particle In Cell simulations.

INTRODUCTION

Short electron bunches produced in a linear accelerator can be directly applied for generation of THz radiation. LUCX accelerator produces short, hundreds of femtosecond duration electron multi-bunch beam, with a variable distance between bunches [1, 2]. In this report we present preliminary measurements performed using only one bunch. Capillary structures capable of producing powerful Cherenkov radiation (ChR) wakefields have been used for THz radiation generation [3] as well as for energy modulation of electron beams [4]. Corrugation in a dielectric capillary allows to produce tunable source of THz radiation based on coherent ChSPR mechanism.

EXPERIMENT

Location of experimental setup is shown in Fig. 1. The capillary was installed in THz chamber which is located in a straight section after RF-gun and solenoid. The radiation was emitted from THz chamber through Fused Quartz vacuum window with 100 mm diameter.

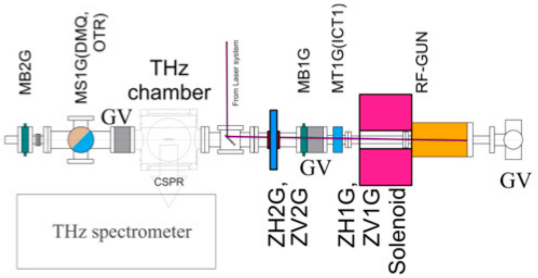

Figure 1: Section of LUCX beamline.

The capillary was constructed as a set of Fused Quartz cylindrical rings with variable internal radius. Optimisation of the corrugation parameters was presented in [5]. The assembled structure was then covered by reflector and attached to the target holders as shown in Fig. 2(a). Fig. 2(b) shows schematic view of the experimental setup. SBD detector was positioned on 200 mm long translation stage at 250 mm distance from the centre of the THz vacuum chamber. During measurements the detector never went beyond the angular aperture of the vacuum window.

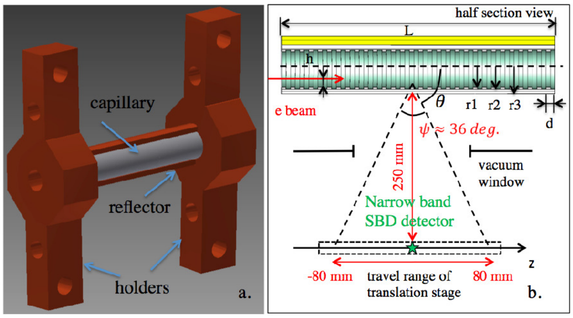

Figure 2: Schematic view of experimental setup and capillary assembly.

Parameters of the THz target and the beam are shown in Table 1. During the experiment the beam propagated through the capillary centre as well as closer to the corrugation. During the off-central propagation the beam impact parameter was approximately 0.5 mm and it moved closer to the capillary boundary not covered by the reflector.

Table 1: Experimental parameters.

Parameter	Value
Beam energy (γ)	16
Beam charge	20 pC
Beam transverse size	200 x 300 μm
Beam longitudinal size	approx. 0.09 mm (300 fs)
Corrugation period, d	1mm
Cylindrical ring width, d/2	0.5 mm
Capil. inter. radii, (r1, r2)	2 and 2.2 mm
Capillary outer radius, r3	2.7 mm
Capillary length, L	30 mm
Capillary material	Fused Quartz
Holder and refl. material	Copper
Bunch impact parameter, h	centre: 2 mm, off-centre: 0.5 mm

ChSPR emitted at angles θ close to 90 deg. follows the dispersion relation:

$$\cos(\theta)=\frac{2\pi m}{kd}+\frac{1}{\beta\sqrt{(\epsilon)}} \tag{1}$$

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where θ is the polar angle with respect to the beam propagation, β is the charge speed in terms of the speed of light, k is the wave number, d is the corrugation period, and m is a diffraction order. $m=0$ corresponds to the Cherenkov peak, and the values $m=\pm n, n=1,2,3..$ correspond to the diffraction orders of SPR. This dispersion relation is only valid for the radiation propagation inside the dielectric material, at the outside boundary it obeys Snell's law of refraction. The relation (1) was originally derived for a corrugated channel in infinite dielectric [6], however in the case of the capillary with finite boundaries it may be applied only at angles θ close to 90 deg .

DISCUSSION

The radiation pattern along axis z (Fig. 2(b)) was measured using narrow band SBD detector. Spectral response of the detector was measured using Transition Radiation (TR) and THz spectrometer (Fig. 1).

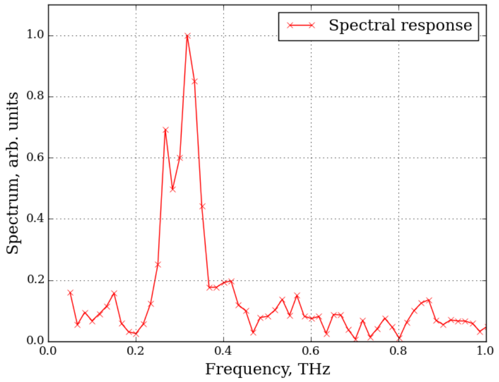

Figure 3: Spectral response of SBD detector.

Fig. 3 shows that spectral response of the SBD detector is in the range 240 – 360 GHz. Fig. 4 shows distributions of the SPR from corrugated capillary with reflector for two beam propagations. When the beam moves closer to the boundary not covered by the reflector, SPR is increased tenfold. In Fig. 4 detZ corresponds to the position of the detector along the axis z (Fig. 2(b)).

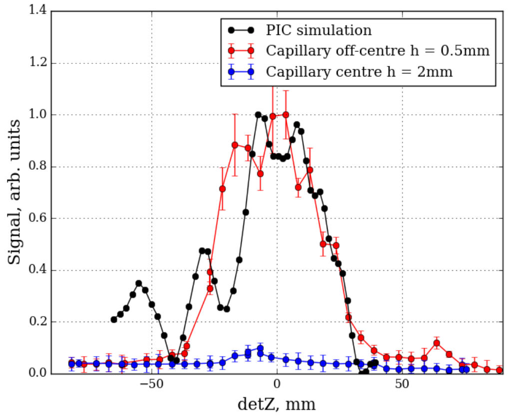

Figure 4: Radiation distribution and its comparison with PIC simulation.

Experimental conditions were simulated using PIC solver of Computer Simulation Technology (CST) software package. The simulated geometry was identical to the realistic one except holders (shown in Fig. 2(a)), which were not taken into account in the simulations. The beam parameters in the simulation were chosen to coincide with those of the experiment, and the beam was moving at 0.6 mm from the corrugation to allow for 3σ beam-corrugation separation. Black curve in Fig. 4 was obtained by calculation of the power spectrum of the emitted radiation in the frequency range 240 – 360 GHz. The radiation directivity pattern for each frequency was calculated as well, hence it was possible to convert power spectrum into the power distribution at the detector locations on the translation stage. Initial power spectrum of the radiation emitted through the surface of the outside boundary, A, of the calculation domain during the simulation time Δt was calculated as follows:

$$P(\omega)=\left|\int_0^{\Delta t}\iint \boldsymbol{S}(\omega)\cdot\boldsymbol{n}\,dA\,dt\right|; \qquad (2)$$

where $\boldsymbol{S}(\omega)$ is Poynting vector, $\boldsymbol{n}$ is unity vector in the outward normal direction from the boundary A. Beam contribution was subtracted from the power distribution of ChSPR.

The calculated and measured power distributions show general agreement in terms of the width and position, however the calculated distribution shows more noticeable oscillating behaviour towards negative values of detZ that correspond to lower frequencies. Because the PIC calculation takes into account all ChSPR radiation emitted from the capillary, not just SPR, it may distort the calculated radiation pattern.

CONCLUSION

In this report we presented measurements and PIC simulations of the SPR from corrugated dielectric capillary with reflector in the frequency range 240 – 360 GHz. Good agreement between the measurement and the simulation was confirmed. It was show that the off-central propagation of the beam provides tenfold increase in the radiated power of SPR compared to the central propagation.

As a continuation of this research future experimental studies will include broadband spectral measurements as well as investigation of the influence the wakefields generated in the capillary have on the electro beam dynamics.

ACKNOWLEDGEMENT

This work was supported by Photon and Quantum Basic Research Coordinated Development Program from the Ministry of Education, Culture, Sports, Science and Technology, Japan, JSPS KAKENHI: 23226020 , 24654076, and also by the Leverhulme Trust International Network Grant IN-2015-012.

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