TUNEABLE QUASI-MONOCHROMATIC COHERENT THZ RADIATION SOURCE DEVELOPMENT

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Abstract

The motivation for developing an intensive THz source at KEK LUCX is coming from the growing interest to THz radiation from various scientific communities worldwide including chemistry, biology, genetics and many more. High gradient photo-cathode RF gun and few tens of femto-second laser system is used to generate a pre-bunched electron beam of a few hundred femto-seconds. We have started to investigate the production of the intense radiation beams in the range of 0.1 – 5 THz based on Coherent Smith-Purcell Radiation (CSPR) using 8 MeV electron beam at KEK LUCX accelerator. CSPR is generated when a charged particle moves in the vicinity of a periodical pattern or grating. The grating type and period can be chosen to make quasi-monochromatic CSPR spectrum. When radiation wavelength is comparable to or longer than the bunch length it become coherent. In this report the status of the experiment, CSPR basic properties and electron beam characterization will be presented.

INTRODUCTION

Intense THz radiation sources such as free-electron lasers are widely used for different applications [1]. Nevertheless, the problem of designing of a non-expensive, compact, wide-range tunable short pulse duration THz sources is not yet solved. A few approaches to design such a source on the basis of laser technologies and electron beam accelerators are now extensively discussed [2]. Also there is a demand from a users community to achieve monochromaticity of generated THz radiation. Undoubtedly the usage of any sort of diffractometers and bandpass radiation filters can reduce output power and introduce undesirable spectra distortions. In this respect the THz source based on Smith-Purcell radiation (SPR) mechanism is promising due to monochromatic emission described by dispersion relation:

$$\lambda_k = \frac{d}{k}\left(\frac{1}{\beta} - \cos\theta\right), \qquad (1)$$

where λ_k, k, d, β and θ are the wavelength, diffraction order, grating period, particle velocity in the light speed units and the observation angle respectively.

The proposal to use coherent SPR generated by a short electron bunches (or by a train of bunches) as the basis of THz radiation sources was made by authors of the work [3]. Certainly, the important characteristic of such sources is its monochromaticity $\Delta\lambda/\lambda$. The relation (1) determines the radiation monochromaticity generated by infinite grating length downstream of a finite aperture $\Delta\theta$:

$$\frac{\Delta\lambda}{\lambda} = \frac{\sin\theta}{1/\beta - \cos\theta}\Delta\theta. \qquad (2)$$

In the case of a finite length grating Nd (N is the number of grating periods) the SPR spectral line monochromaticity will be defined as:

$$\frac{\Delta\lambda}{\lambda} \approx \frac{1}{kN}. \qquad (3)$$

Usage of the high diffraction order ($k > 1$) allows to narrow the coherent SPR spectral line $\delta\lambda$. Hence the main objective of this paper is to show a possibility to produce SPR beams with a monochromaticity better than a few % choosing the high diffraction order.

EXPERIMENTAL RESULTS

The measurements were done at the Laser Undulator Compact X-ray facility (LUCX) at High Energy Accelerator Research Organization (KEK), Fig. 1. LUCX is a multipurpose linear electron accelerator facility initially constructed as a RF gun test bench and later extended to facilitate Compton scattering [4] and coherent radiation generation [5] experiments. It consists of RF gun [6], which was designed to produce a multi-bunch (2.8ns separation) high quality electron beam with up to 1000 bunches, a 0.5 nC charge per bunch, and ~ 10 MeV beam energy. This beam can be then accelerated to 30 MeV by the normal conductivity compact linear accelerator [7]. Two klystrons are used for the RF gun and accelerating structure. Also, two laser systems: picosecond Nd:YAG and femtosecond Titanium-Sapphire were employed for different LUCX operation modes.

Table 1 summarizes electron beam parameters in femtosecond operation mode. Short electron bunches were generated in the RF gun via photocathode illumination by the femtosecond laser pulses with wavelength of about 266 nm. Then electron bunches were accelerated to the energy of approximately 8 MeV in the 3.6 cell RF gun. The experiment

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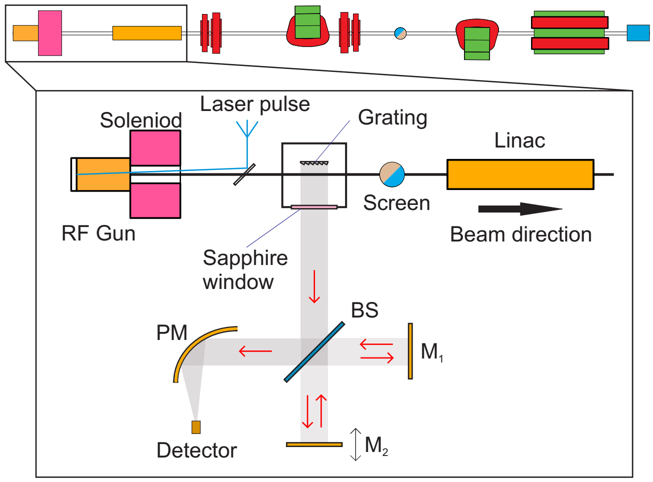

Figure 1: LUCX beamline and experimental schematics. Abbreviations: M_1 - fixed interferometer mirror, M_2 - movable interferometer mirror, BS - splitter, PM - off-axis parabolic mirror.

was performed with the beam parameters given in Table 1 except that number of micro-bunches was set to 1. The longitudinal electron bunch profile measurements method was well described in [8]. Two Schottky barrier diode detectors with different regions of spectral sensitivity 60 – 90 GHz and 320 – 460 GHz were used in the experiment. Detailed parameters list is shown in Table 1.

Table 1: LUCX Beam Parameters in fs Operation Mode and SBD Detectors Characteristics.

Beam energy, typ.	7 MeV	
Micro-bunch charge and stability	25 pC, 6 %	
Number of micro-bunches, max	4	
Bunch length, min	160 fs	
Normalized emittance, $\epsilon_x \times \epsilon_y$	1.5×1 πmm mrad	
Parameter	SBD #1	SBD #2
Frequency range	60 – 90 GHz	320 – 460 GHz
Wavelength range	3.3 – 5.0 mm	0.94 – 0.65 mm
Response time	~ 250 ps	sub-ns
Antenna gain	24 dB	25 dB
Input aperture	30 × 23 mm	4 × 4 mm
Video sensitivity	20 V/W	1250 V/W

The vacuum chamber equipped with the sapphire vacuum window which provided aperture of 145 mm. 5-axis manipulator was used for fine adjustment of the target's position in 3 orthogonal directions and in two rotation angles of the target with respect to electron beam propagation direction. In the case of SPR geometry, the distance between grating and the electron beam was set to 0.6 mm. The radiation spectral characteristics were measured by the Michelson interferometer (described in [9]) installed directly in front of the chamber vacuum window (see Fig. 1). To generate coherent Smith-Purcell radiation the 60 × 30 mm target was placed in the vacuum chamber. The back side of the target was flat to confirm transition radiation (TR) characteristics. The TR spectrum emitted by a single electron is assumed to

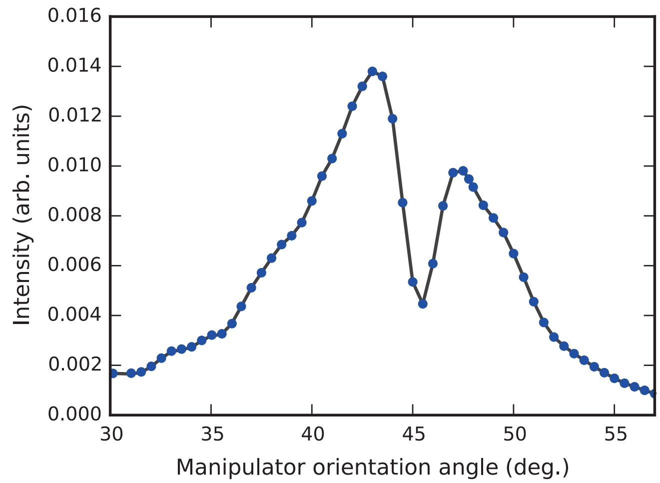

Figure 2: TR orientation dependence measured in the range 320 – 460 GHz.

be constant within detector sensitivity bands. Therefore the measured normalized TR spectrum was used as a spectral efficiency of the entire measurement system, including spectral transmission efficiency of the vacuum window, detector wavelength efficiency, and so on. The SPR resonances $k = 1$ and $k = 5$ lie within the detector sensitivity bands. Figure 2 shows the typical TR orientation dependence obtained with detector SBD 320 – 460 GHz. The spectral measurements by means of Michelson interferometer were done at the maxima of orientation dependence. To reconstruct spectra from auto-correlation measurements Fourier Transform algorithm was used.

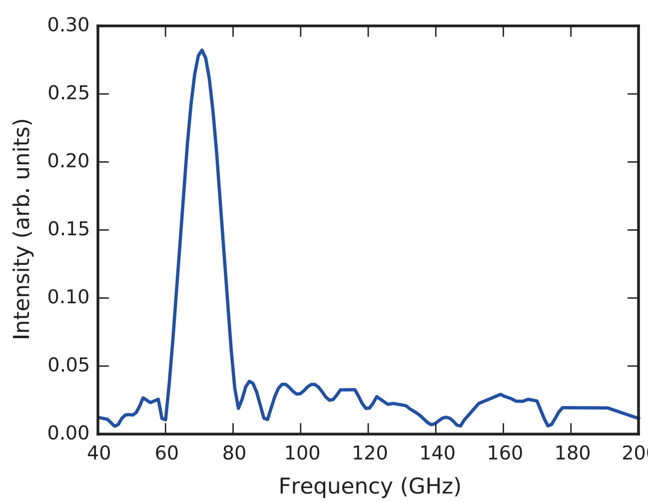

Figure 3: SPR reconstructed spectrum in the range of 60 – 90 GHz.

Two normalized SPR spectra measured in a range of 60 – 90 GHz and 320 – 460 GHz are shown in Fig. 3 and Fig. 4. Analyzing obtained spectra it is possible to find relative line widths $\Delta\lambda/\lambda_1 = 15\%$ for 60 – 90 GHz and $\Delta\lambda/\lambda_5 =$

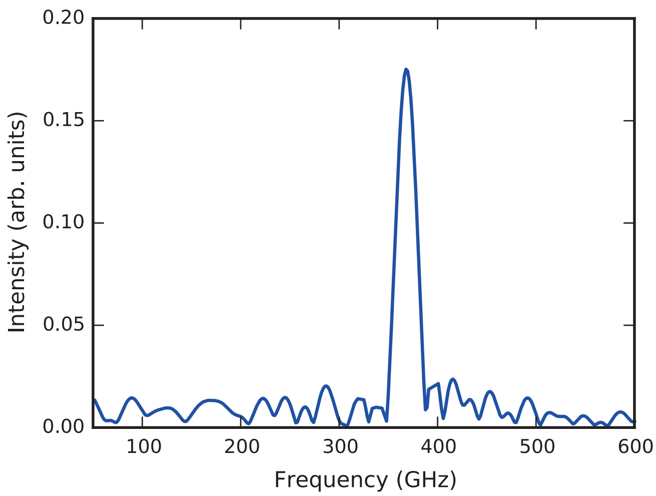

Figure 4: SPR reconstructed spectrum in the range of 320 – 460 GHz.

6% for 320 – 460 GHz. As one can see the spectral peak measured in a range 60 – 90 GHz corresponds to $k = 1$ and the spectral peak measured in 320 – 460 GHz range corresponds to the 5th SPR resonance $k = 5$.

CONCLUSION

We have investigated coherent SPR spectral characteristics both theoretically and experimentally. Our experimental apparatus includes the Michelson interferometer with SBD detectors. The spectral range and efficiency of each detector were investigated experimentally measuring coherent transition radiation spectrum. We have compared intensities of coherent TR and coherent SPR in mm range measured in identical conditions and showed that the brightness is practically comparable for both mechanisms. Our simulations show that the intensity of the fifth order spectral line is about two times smaller in comparison with the line intensities of the first and the second orders. Some adjustment of the SPR line can be achieved by the grating tilt angle $\theta_{gr} \ll 1$.

ACKNOWLEDGMENTS

This work was supported by the Photon and Quantum Basic Research Coordinated Development Program from the Ministry of Education, Culture, Sport, Science and Technology, Japan, JSPS KAKENHI: 23226020 and 24654076, JSPS and RFBR under the Japan-Russia Research Cooperative Program (no. 15-52-50028 YaF_a), the Leverhulme Trust through the International Network Grant (IN−2015 − 012) and the European Union Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 655179.

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