INVESTIGATION OF COHERENT DIFFRACTION RADIATION IN RESONANT CONDITIONS FOR DEVELOPING OF AN INTENSE MONOCHROMATIC RADIATION SOURCE

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Abstract

The motivation for developing of intense THz source at KEK LUCX is coming from the growing interest to THz radiation from various scientific communities worldwide. High gradient photo-cathode RF gun and few tens of femtosecond laser system are used to generate a pre-bunched electron beam of a few hundred femtoseconds. We are investigating the production and properties of the intense radiation beams in the range of 0.1 − 5 THz based on Grating Diffraction Radiation (GDR) in a single bunch regime of the 8 MeV electron beam at KEK LUCX accelerator. GDR 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 GDR spectrum. In the contrast to conventional Smith-Purcell radiation, GDR has much higher frequency tunability with comparable output pulse energy. In this reports the status of the experiment and GDR basic properties including polarization characteristics will be presented.

INTRODUCTION

Conventional accelerator-based THz sources can provide sub-picosecond μJ-level radiation pulses with continuous spectrum up to and beyond 1 THz [1] what is in high demand for a various applied studies in biology and medicine. However, narrow-band high intensity THz sources are also desired [2]. The simplest approach is to employ a THz monochromator with associated reduction in available THz energy per pulse. Much more efficient approach is to use intrinsically monochromatic emission mechanism like Smith-Purcell radiation (SPR) [3]. The use of coherent SPR generated by short electron bunches (or by a train of bunches) as the basis of THz radiation sources was proposed by authors of the Refs. [4, 5]. Coherent radiation emission occurs when the bunch length is comparable to or shorter than the radiation wavelength resulting in the SPR intensity being determined by the square number of electrons per bunch.

To achieve greater EM radiation frequency tuning range in comparison with typical SPR it was decided to use grating edge as a radiator. In this case inclination of a grating relative to a beam changes GDR spectral lines frequency for the given outgoing photon angle in accordance with the generalized dispersion relation [6]:

$$\lambda_k = \frac{d}{k}\Big(\frac{\cos\theta}{\beta} - \cos(\eta - \theta)\Big), \tag{1}$$

where λ is the radiation wavelength, d is the grating period, k is the diffraction order, β is the electron velocity in the speed of light units, θ is the grating inclination angle, η is the observation angle. Produced radiation by analogy with the grating transition radiation [7] is referred as Grating Diffraction Radiation or GDR. From Eq.(1) the monochromaticity of the GDR spectral line $\Delta\lambda_k/\lambda_k$ should be proportional to $1/kN$ for the finite length grating Nd. Using full width at half maximum (FWHM) as an absolute spectral line width, the monochromaticity is defined as [8]:

$$\frac{\Delta\lambda_k}{\lambda_k} = \frac{\Delta\nu_k}{\nu_k} = \frac{0.89}{kN}, \tag{2}$$

stating that the higher GDR diffraction orders should have higher monochromaticity.

EXPERIMENTAL RESULTS

The measurements were done at KEK LUCX facility at High Energy Accelerator Research Organization (KEK), Fig. 1. KEK LUCX is a linear electron accelerator facility. Schematic diagram of the experimental setup are shown in Fig. 1. Short electron bunches were generated by the Cs_2Te photocathode illuminated with the femtosecond laser pulses of 266 nm wavelength [9–11]. Then electron bunches were accelerated to the energy of 8 MeV in the 3.6 cell RF gun. The experiment was conducted with electron beam parameters given in Table 1.

The Michelson interferometer system bandwidth 150 GHz was confirmed by measuring broadband CTR spectrum at

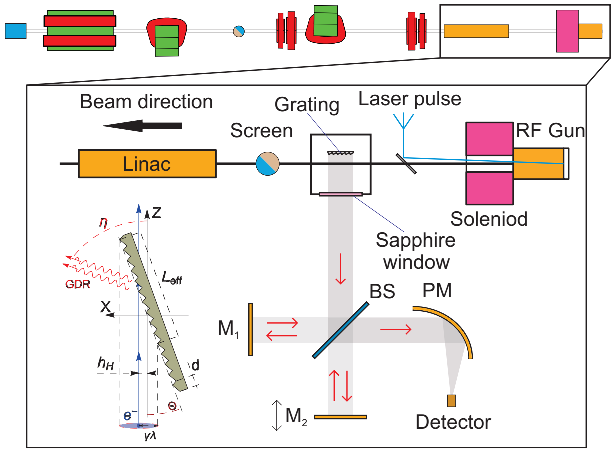

Figure 1: Experimental setup; *Left*: target geometry, *Right*: LUCX beamline and experimental schematics. M_1 - fixed and M_2 - movable interferometer mirrors, *BS* - beam splitter, *PM* - off-axis parabolic mirror.

Table 1: LUCX Beam Parameters and SBD Detectors Characteristics

Beam energy, typ.	7 MeV	
Bunch charge Q, stability	25 pC, 6 %	
Number of bunches,	1	
Bunch duration,	250 fs	
Norm. emittance, $\epsilon_x \times \epsilon_y$	1.5×1 πmm mrad	
SBD parameters		
Frequency range, GHz	60 – 90	320 – 460
Wavelength range, mm	5 – 3.33	0.94 – 0.65
Response time, ps	~ 250	
Antenna gain, dB	24	25
Input aperture, mm	25×16	4×4
Video sensitivity, V/W	2300	1250

the θ corresponded to the maximum of CTR yield, Fig. 2. At the same figure the spectra of coherent SPR and GDR (both horizontal polarizations) are shown for the same impact parameters $h_h = 0.6$ mm, $h_v = 0.5$ mm, and $\theta = 0°$). For these parameters the dispersion relation Eq.(1) reduces to the well-known Smith-Purcell relation. As expected, the spectral line frequencies of SPR and GDR coincides. However, the intensity of GDR at $\theta = 0°$ is smaller since the only part of the beam Coulomb field interacts with the grating. For a different grating inclination angles and different polarizations intensity varies, as can be seen from the θ-scans performed for two polarizations while keeping $h_v = 0.5$ mm, Fig. 3 and Fig. 4.

Figure 5 shows the summary of all spectral measurements performed with 320 – 460 GHz and 60 – 90 GHz SBD detectors. Obtained measurement results demonstrate almost 100% linear polarization of the CTR (horizontal polarization) along the direction of specular reflection and reduction of linear polarization down to 11% for GDR (vertical polarization for a small grating inclination angles θ). From this it

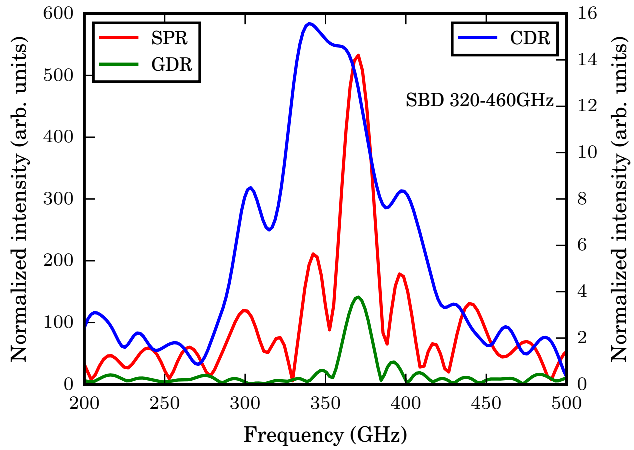

Figure 2: Comparison of the CTR, SPR and GDR spectra.

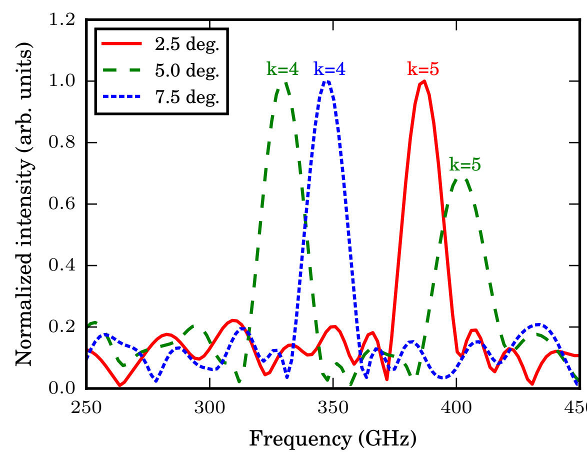

Figure 3: Normalized GDR spectral lines (horizontal polarization) measured for different grating inclination angles.

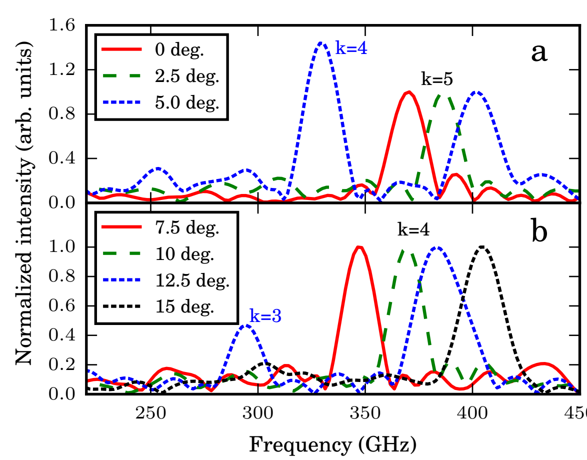

Figure 4: Normalized GDR spectral lines (vertical polarization) measured for different grating inclination angles.

is possible to conclude that in this direction the radiation is elliptically polarized, whereas experimental results confirm the high degree of coherence and the degree of coherent radiation polarization when registering with a finite aperture detector does not noticeably change. Above result is in good agreement with theory presented in [12].

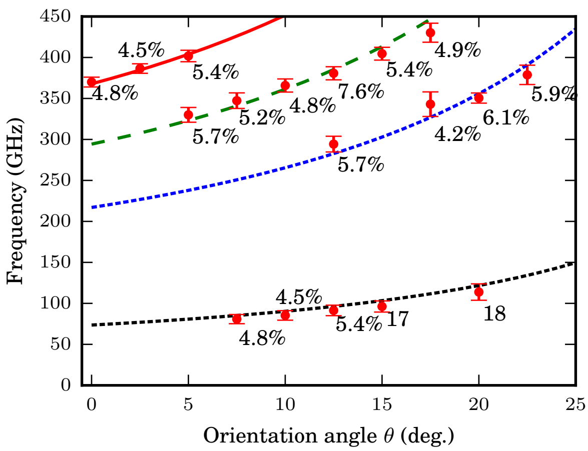

Figure 5: The dispersion relation calculated by Eq.(1) for different diffraction orders as: k = 5 - red solid line, k = 4 - green dashed line, k = 3 - blue dashed line, k = 1 - black dashed line. Points represent the peak positions and spectral bandwidth.

CONCLUSION

We have investigated coherent Grating Diffraction Radiation spectral characteristics both theoretically and experimentally. Our experimental apparatus includes the Michelson interferometer with two SBD detectors. We have compared intensities and spectra of CTR, SPR and GDR measured in identical conditions and showed that it is possible to achieve quasi-monochromatic GDR emission with wide tuning range. The obtained results follow the generalized dispersion relation Eq.(1). For the case when electrons directly interacts with a grating the resulting radiation is monochromatic (so-called grating transition radiation [7]) and the dispersion relation Eq.(1) also remains valid . However, GDR is more promising since there is no direct interaction of a beam with a target.

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