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STATUS OF TEST-ACCELERATOR AS COHERENT THz SOURCE (t-ACTS) AT ELPH, TOHOKU UNIVERSITY

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Abstract

A test-Accelerator as Coherent Terahertz Source (t-ACTS) has been under development at the Research Center for Electron Photon Science (ELPH), Tohoku University, in which an intense coherent terahertz radiation is generated from the femtosecond electron pulses. Velocity bunching scheme in a traveling wave accelerating structure is employed to generate the short electron pulses, and then the generation of femtosecond electron pulses was confirmed by spectrum analysis of coherent transition radiation using Michelson interferometer. Coherent transition radiation and coherent undulator radiation in the terahertz (THz) region from the short electron pulses have been demonstrated, and their characteristics such as frequency spectrum, spatial distribution and polarization were measured and compared with theoretical calculations. We have succeeded to generate the coherent transition radiation up to approximately 5 THz and the coherent undulator radiation of narrow bandwidth with a center frequency 3 THz. At present, development of a variable polarized THz source using a crossed-undulator system is being carried out. In addition, we have conducted a beam experiment for very short period undulator. The status of t-ACTS is presented in this conference.

INTRODUCTION

Terahertz (THz) radiation sources have attracted considerable interests recently, because of their potential applications in material science, medical imaging, communications, etc. THz radiation can be generated with various ways. In recent years, a compact, high average power terahertz sources based on a solid laser have been remarkably developed. The average output power of the injection-seeded THz-wave parametric generator (is-TPG) has reached 10 kW. On the other hand, accelerator-based terahertz sources with large peak power have been advanced such as free electron laser with optical resonator. With the increasing power of terahertz sources, their applications are not limited to analysis etc., and have been used to change the structure and function of materials.

In many terahertz sources, one of the most efficient sources is the electron pulse of relativistic energy produced by an accelerator. A short electron pulse can produce coherent radiation at wavelengths longer than electron pulse length with the intensity proportional to the square of the number of electrons contained in a pulse. Electron population in the pulse is typically the order of 10^7–10^{10} electrons, therefore high intense terahertz radiation is emitted form a short electron pulse [1]. In this paper, we report the extremely short electron pulse generation and the development of coherent terahertz souse.

EXTREMELY SHORT ELECTRON PULSE

Generation of Short Electron Pulses at t-ACTS

The accelerator system of t-ACTS consists of an S-band thermionic RF gun, an alpha magnet with energy collimation, 3m-long travelling wave accelerating structure. Velocity bunching scheme is employed for extremely short electron pulses production [2]. A thermionic RF gun, which composed of two cavities, was specially designed to manipulate a longitudinal phase space distribution of electron pulses. The RF phases and amplitude in the cavities can be tuned independently. The special RF gun is capable of producing electron pulses having a longitudinal phase space distribution suitable for velocity bunching in the accelerating structure. According to a numerical simulation, 50 fs electron pulse can be produced by the t-ACTS accelerator configuration.

Electron Pulse Length Measurements

The electron pulse length has been measured by a streak camera, which is widely used to measure a pulse length using an optical transition radiation. Although the streak camera has the feature that it can measure the pulse length in one shot, the temporal resolution is not enough to measure femtosecond electron pulse. We used a streak camera only to measure the relationship between the compressed electron pulse length and the injection phase of the beam to accelerator structure [3].

Femtosecond electron pulse produces a characteristic terahertz radiation when appropriately disturbed, and then information of the longitudinal pulse shape can be obtained, since the resulting radiation spectrum is related to the form factor. We measure a spectrum of coherent transition radiation, and estimate the electron pulse length. Michelson interferometer was installed to obtain an interferogram of the

Table 1: Electron Beam Parameters

Macropulse length	~2.0 μs
Number of bunches	~5700 bunches/macropulse
Beam energy	30~50 MeV
Bunch charge	3 ~ 4 pC
Bunch length (σ_z)	0.05~ 2 ps

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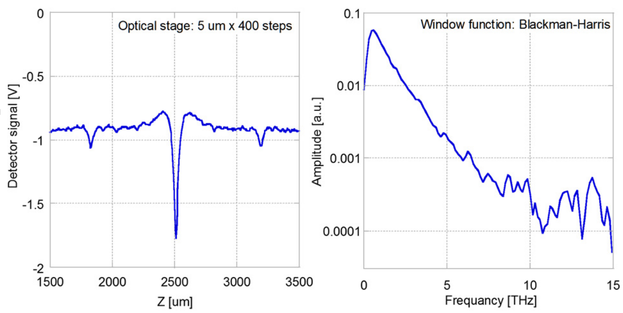

Figure 1: (Left) Measured interferogram of transition radiation and (Right) Radiation spectrum.

coherent transition radiation. Figure 1 shows an example of measured interferogram and the spectrum derived by Fourier transform of the interferogram. In this measurement, a frequency range and a resolution were 15 THz and 75 GHz, respectively. The radiation spectra extends to over 5THz. We try to fit the form factor function assuming Gaussian bunch to the spectrum data. In the spectrum measurement, it is necessary to consider that low frequency component is suppressed due to causes such as a sensitivity of the detector and aperture in the interferometer. The fitting function is defined as product of form factor for Gaussian bunch and low-frequency cut-off function [4]. From the fitting results, it was confirmed that an electron pulse of approximately 80 fs was generated. Although the Gaussian shape of electron pulse was assumed in this analysis, it is expected from simulation studies that the actual beam is slightly different with the Gaussian distribution. As the next step, analysis methods using Kramers-Kronig transformation should be considered without assuming Gaussian pulses [5].

GENERATION OF HIGH INTENCE COHERENT THZ RADIATION

Coherent Transition Radiation

As mentioned in the previous section, the coherent transition radiation in terahertz region was emitted from the compressed electron pulses. Intensity of transition radiation was measured as a function of microbunch charge. It showed a quadratic dependence expected for coherent radiation [6]. Spatial distribution of transition radiation was measured by scanning detector position across the radiation axis. Polarization components in both the horizontal and the vertical were measured by installing a free standing wire-grid polarizer (GS57207, wire diameter: 10 μm, wire spacing: 25 μm, SPECAC) in front of the pyroelectric detector (PYD-1 [PHLUXi]). Figure 2 shows the measured spatial profile of CTR with and without the wire grid polarizer. These measured spatial profiles clearly show that the CTR is radially polarized radiation. In addition, it has been confirmed that CTR can be easily focused to approximately same size with wavelength by using a terahertz lens. This CTR can be used for a broadband THz spectroscopic imaging.

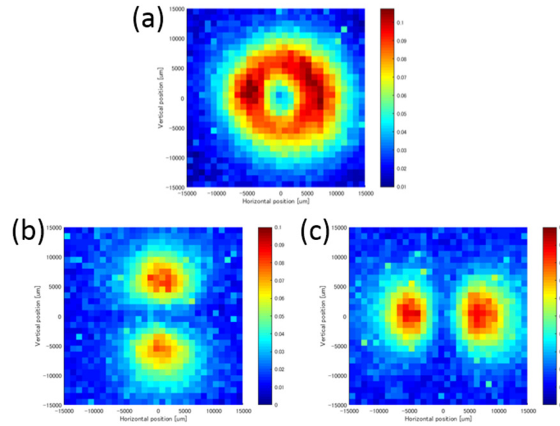

Figure 2: (a) Measured spatial distribution of CTR without the wire grid polarizer. (b) and (c) are measured vertical and horizontal components of CTR.

Coherent Undulator Radiation

To produce the THz undulator radiation, the K-value and a period length of undulator have to be large. We have developed the THz undulator, which is a planer undulator of Halbach type made only of permanent magnet (Nd-Fe-B) blocks with TiN coating. The period length of the undulator and the number of periods are 100 mm and 25, respectively. Each magnet block size is 110×65×25 mm^3. The gap can be varied in the range of 54~110 mm, where the minimum gap is limited for installation of beam pipe. The peak of magnetic field strength is approximately 0.41 T at the minimum gap.

The frequency spectrum of the undulator radiation was measured in Michelson interferometer [7]. Entire of interferometer system is enclosed and continually purged with dry nitrogen to avoid the strong absorption of THz wave by water vapor. Figure 3 shows measured interferogram with different undulator gap, moving the mirror in 5μm step over 5 mm. This interferogram indicates that coherent undulator radiation was being produced. Figure 3 (Right) shows the spectrum of the coherent undulator radiation and a frequency resolution of the spectrum was 29.97GHz in this measurement. Center frequency of the radiation was approximately 2.69 THz (λ=111μm) with 54 mm gap and

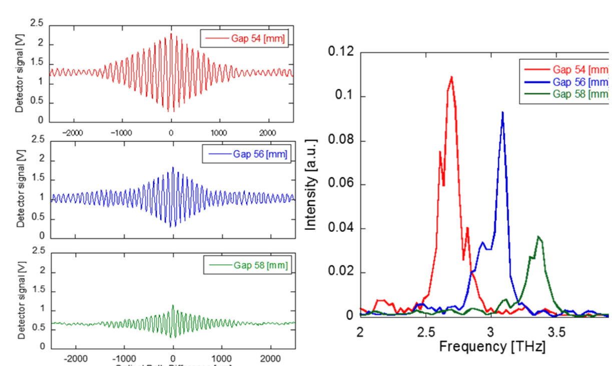

Figure 3: (Left) Interferogram and (Right) spectrum of coherent undulator radiation with different gaps.

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a frequency spread was 0.13 THz (FWHM). By varying the undulator gap, a frequency shift of the coherent undulator radiation was investigated. The frequency of the radiation changes as a function of undulator strength parameter K as shown in Fig. 3 (Right). As radiation frequency became higher, the radiation power rapidly decreases, because the form factor gets smaller for the higher frequency. This frequency dependence of the intensity is also indicates that the measured undulator radiation is a coherent radiation.

Polarization Control of THz Undulator Radiation

Right and left circularly polarized THz sources are very useful for biological analysis. Vibrational circular dichroism (VCD) measurements in the THz region are extremely sensitive to conformational changes in proteins. We are developing two different types of terahertz sources that can generate arbitrary polarization states by utilizing the coherence of undulator radiation. One generates horizontal and vertical polarized coherent undulator radiation using a crossed undulator. By adjusting their relative phase and superimposing, an arbitrary polarization state can be obtained. This terahertz source using a crossed-undulator will be presented in detail in this conference [8]. Another terahertz source manipulates the polarization utilizing a linearly polarized radiation from one undulator using Martin-Puplett interferometer employed as a phase shifter. The configuration of this polarization controller is shown in Fig. 4. The demonstration experiments for these polarization variable sources will be conducted at t-ACTS later this year.

BEAM TEST OF VERY SHORT PERIOD UNDULATOR

A very short period undulator has been developed Dr. S. Yamamoto in KEK [9]. Undulator field is produced by pair of a100 mm long monolithic undulator magnet plate with 4-mm periods length. Magnetic fields is approximately 3 kG at a gap of 1.6 mm. Beam experiments for light generation using the real electron beam have been carried out at t-ACTS. The first observation and characterization of the light was performed successfully. Figure 5 shows the undulator radiation using a color CCD camera. A spectrum

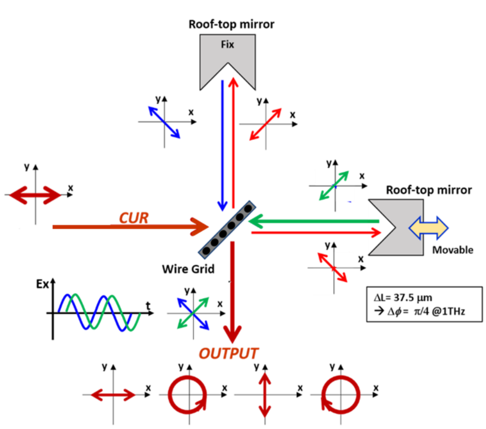

Figure 4: Polarization controller employing a Martin-Puplett interferometer.

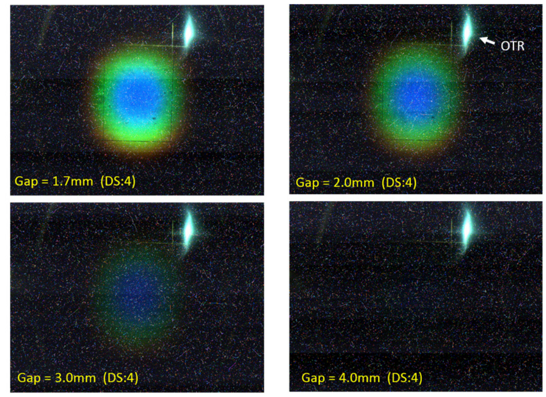

Figure 5: Observed the undulator radiation with different gap using a color CCD camera.

was measured using imaging spectrometer and the spectra of the first harmonics was around 2.65 eV with 33.5 MeV electron beam.

SUMMARY

Coherent THz sources with different band-width utilized extremely short electron pulse have been developed at t-ACTS. We will demonstrate a variable polarization THz source utilizing the features of coherent undulator radiation. Furthermore, development of non-destructive beam monitors applying a coherent radiation is in progress [10].

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