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DEVELOPMENT OF A DETECTION SYSTEM FOR QUASI-MONOCHROMATIC THz PULSE BY A SPATIALLY MODULATED ELECTRON BEAM

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Abstract

We have studied the generation of the broadband Terahertz (THz) pulse using a compact linear accelerator. The THz pulse is generated by control of an electron beam angle to Cherenkov radiation angle. In addition, we have succeeded in producing a quasi-monochromatic THz pulse by the spatially modulated electron beam by passing through a slit. This work aims to develop a detection system to elucidate the spectrum of the quasi-monochromatic THz pulse. To detect it stably in a noisy radiation environment, the stability of probe laser system for Electro Optic (EO) sampling and timing synchronization system are important. In this conference, the generation method of each THz pulses, the results of development of detection system, and future prospect will be reported.

INTRODUCTION

Terahertz (THz) wave is permeable like radio wave and travels in straight line like light because its frequency range lies between them. In addition, it has fingerprints spectrum originated from characteristic absorption peaks specific to the substances such as the excitation energy of intermolecular vibrations. These characteristics are expected for applied research, for instance, transmission imaging technology [1] and morphological change [2]. Accelerator-based THz light sources are attractive because they can produce the high intensity pulses needed for these applications. However, the small number of these facilities restrict opportunities to use them.

With the aim of improving this situation, we are trying to develop the compact monochromatic THz light source. The THz pulse have been generated by utilizing coherent Cherenkov radiation with electron beams of 4.8 MeV from a photocathode rf-gun. Furthermore, we have generated a quasi-monochromatic THz pulse from spatially modulated electron beam using a slit. However, the quasi-monochromatization of the THz pulse is only confirmed by using a few bandpass filters. Therefore, this study aims to reveal the spectral characteristics of quasi-monochromatic THz pulse.

THz PULSE GENERATION

Broadband THz Pulse from the Tilted Electron Bunch

We have utilized coherent Cherenkov radiation to generate a THz pulse. Coherent radiation is obtained when an electron bunch size is sufficiently smaller than the wavelength of the radiation, leading to the increase of the intensity from an electron bunch. We utilize the Cherenkov radiation by way of the THz pulse generation. When an electron travels faster than the phase velocity of light in the medium, the Cherenkov radiation occurs at the specific radiation angle, called the Cherenkov angle θ_c, which is as follows [3]:

$$\theta_c = \cos^{-1}\left(\frac{1}{n\beta}\right), \tag{1}$$

where $\beta(= v/c)$ is the relative velocity of the electron to the phase velocity of light and n is the refractive index of the medium. The tilt control of the electron bunch can match the phases of the radiations from each electron in an electron bunch. When the electron bunch is tilted to the Cherenkov angle, the coherent radiation depending on the beam size is obtained as shown in Fig. 1. The beam size of our electron bunch is typically about 300 µm, which corresponds to 1.0 THz band so we can generate the broadband THz pulse less than 1.0 THz.

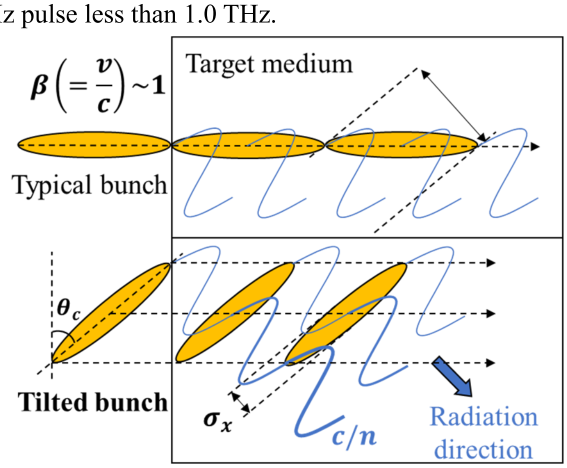

Figure 1: Schematic principle of THz pulse generation by coherent Cherenkov radiation.

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Quasi-monochromatic THz Pulse Using a Slit

We have also studied the generation of the quasi-monochromatic THz pulse in combination with the method in Fig. 1 and the control of the spatial structure. Figure 2 shows the schematic diagram of the quasi-monochromatization. The electron bunch is spatially modulated by passing through a slit as shown in Fig. 3. The spatial modulated electron bunch is tilted with keeping that structure. When that bunch generates the THz pulse in the target medium, the spatial structure is converted to the time-domain structure. Therefore, the spatial modulated electron bunch using the slit can generate the quasi-monochromatic THz pulse corresponding to the slit period. The parameters of the slits are shown in Table 1.

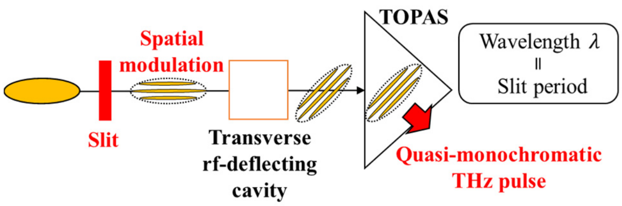

Figure 2: Schematic principle of quasi-monochromatic THz pulse generation.

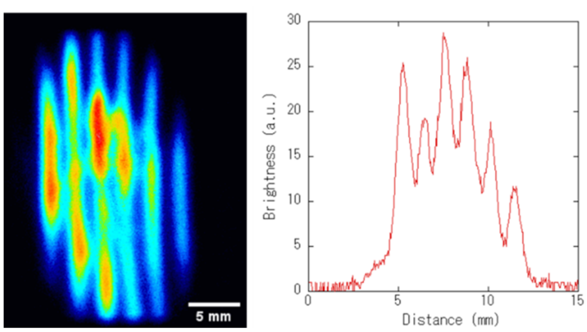

Figure 3: The profile (left) and calculation data (right) of the spatial modulated electron bunch using the slit 1.

Table 1: Parameters of the Slits

	Slit 1	Slit 2
Slit period	1.3 mm	0.8 mm
Corresponding frequency	0.2 THz	0.3 THz
Thickness	2 mm	
Material	Stainless steel	

ELECTRO-OPTIC SAMPLING

EO sampling is an effective detection method which can obtain both the amplitude and the phase of the THz pulse electric field simultaneously. The birefringence corresponding to the electric field strength of the THz pulse changes the polarization of the probe laser in the EO crystal. The probe laser is split by polarization beam splitter (PBS) into s- and p-polarization, and the changes of each polarization are detected by two photo diodes (PD). The time-domain waveform of the quasi-monochromatic THz pulse can be sampled by scanning the timing of the probe laser [4].

Beamline Layout

As shown in Fig. 4, a picosecond electron bunch is generated using a S-band photocathode rf electron gun. A picosecond laser (262 nm) generated by passing through two BBO crystals excites the Cs-Te photocathode at 5 Hz and the electron bunch is accelerated to 4.8 MeV. A transverse rf-deflecting cavity is used for the control of the angle of the electron bunch. We adopted TOPAS as a target medium, which has low absorption (α <0.1 cm^{-1}) and a constant refractive index (n=1.53) across the THz band [5]. The Cherenkov angle calculated from the electron beam energy of 4.8 MeV and the refractive index of TOPAS of 1.53 is 49 deg.

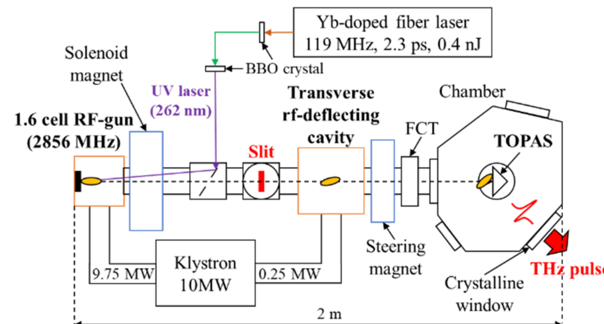

Figure 4: Schematic layout of the beamline.

Experimental Setup for EO Sampling

The experimental setup for time-domain measurement by EO sampling is shown in Fig. 5. The pellicle beam splitter achieves the collinear incidence of the quasi-monochromatic THz pulse and probe laser pulses. EO crystal is 1 mm <110> oriented Zinc telluride, which can detect up to approximately 1 THz [4]. An optical delay stage scans the timing of the probe laser at 100 fs steps. The balance detection system consists of a quarter wave plate, a polarization beam splitter and two photo diodes.

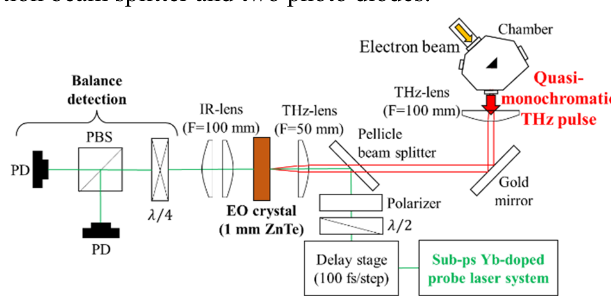

Figure 5: Schematic of the EO sampling setup.

Results and Discussion

The probe laser system consisted of the oscillator, the fiber amplifier, and the compressor using the transmission grating pair has already been constructed. Its parameters are shown in Table 2. Currently, the time-domain waveform of the quasi-monochromatic THz pulse could not be obtained by EO sampling. The reason is considered as below two factors. The first was the lack of the intensity of the quasi-monochromatic THz pulse. The number of electrons of spatially modulated electron bunch is less than

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those of an unmodulated bunch. In our monochromatization method, even if the overall charge is same to an unmodulated bunch, each micro bunch has smaller charge. Therefore, the electric field of monochromatic THz pulse becomes lower, making it difficult to obtain its time-domain waveform. The second was the overall timing synchronization accuracy. It was 7.9 ps (For the photocathode UV laser: 7.9 ps, the probe laser: 650 fs). The required accuracy of the synchronization system is sub-ps because the pulse duration of the probe laser is sub-ps. Therefore, the timing synchronization system has to be improved and the solution of this problem is explained later.

Table 2: Parameters of the Probe Laser

Center wavelength	1030 nm
Repetition rate	39.66 MHz
Pulse energy	3.7 nJ
Pulse duration (FWHM)	180 fs

PHOTOCONDUCTIVE ANTENNA

We are also planning to conduct the time-domain waveform of the quasi-monochromatic THz pulse by using the photoconductive antenna (PCA). PCA with a single gap of the electrodes can emit the THz wave by inducing the photo-induced charge carriers which only occur under circumstances injecting the pulse laser. Furthermore, it can obtain the THz electric field by measuring the current change induced by THz pulse under same circumstances [6]. The result of its time-domain waveform by using the PCA can be regarded as the reference data of the result by EO sampling.

Experimental Setup Using PCA

The experimental setup using the PCA is shown in Fig. 6. In this setup, the Yb-doped fiber laser works as both the pomp laser exciting the photocathode and the probe laser for the time domain measurement. This consolidation of two timing synchronization systems can improve the its accuracy to sub-ps. Furthermore, we are going to conduct the time-domain measurement of the quasi-monochromatic THz pulse in this timing synchronization system by EO sampling.

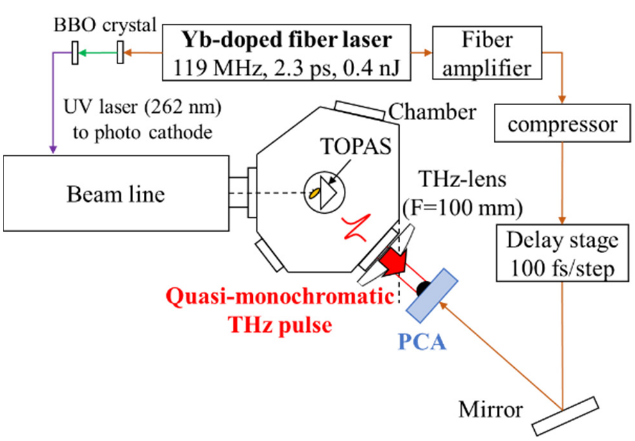

Figure 6: Schematic of the detection system using PCA.

CONCLUSION

The time-domain measurement of the quasi-monochromatic THz pulse, which is generated by spatial modulation of the tilt-controlled electron beam, was not successful by EO sampling. However, we improved the timing synchronization accuracy to the required level of sub-ps.

In near future, we are going to try to conduct the time-domain measurement of the quasi-monochromatic THz pulse by using the PCA. The new system using the PCA is supposed to improve the timing synchronization accuracy. At the same time, we are going to try again the same experiment in the new timing synchronization system by EO sampling.

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