Measurement of Coherent Transition Radiation from Electron Beam Using Large-apeture Photoconductive Antenna

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Abstract— **Generation of femtosecond electron bunches has been investigated for a light source based on electron bunches and improvement of time resolution in time-resolved measurements. In this study, temporal electric fields from electron bunches using a photoconductive antenna (PCA) with radial microstructures were measured. Radially polarized terahertz (THz) pulses from femtosecond electron bunches were generated by coherent transition radiation (CTR). Electric-field-induced current from the PCA depending on THz electric field was measured.**

I. INTRODUCTION

SHORT electron bunches with durations of femtoseconds are key elements for the development of high-quality and intense light sources for applications in accelerator physics such as free-electron lasers [1]. Pulsed electron bunches can be also applied to time-resolved pump-probe experiments involving the application of techniques such as ultrafast electron diffraction [2] and pulse radiolysis [3] for improving the time resolution of each system. To improve the time resolution in time-resolved measurement, diagnostics of electron bunches are essential. Previously, electro-optic (EO) sampling [4], which is one of detection techniques of THz light pulse, is used in diagnostics of electron bunches [5]. In EO samplings, the birefringence of EO crystals is induced by the beam electric field, and laser polarization corresponding to the longitudinal electron beam profile is detected. EO monitors based on the temporal decoding have revealed the Coulomb field of a root mean square (rms) width of 60 fs from femtosecond electron bunches [6]. Photoconductive antennas (PCAs) are widely used for both generation and detection of terahertz (THz) pulses [7]. Recently, fabrication of a large-aperture PCA and generation of radially polarized electric fields were reported [8,9]. The application of PCAs to the detection of THz pulses from electron bunches will be a new methodology for beam diagnostics.

In this paper, analysis of the electric field profile of coherent transition radiation (CTR) using a large-aperture PCA with micro-structured electrodes is investigated. THz pulses of CTR were generated at an interface of aluminum mirror. The PCA enables the detection of radially polarized THz pulses with adequate sensitivity according to the geometry of electrodes. Photo-induced charge carriers were generated by irradiation of a femtosecond laser on the PCA. Electric-field-induced current was obtained as THz electric field strength of CTR at the duration of the laser irradiation. CTR was emitted by femtosecond electron bunches from a photocathode-based linac. Time-domain measurements on electron bunches of 32 MeV and 170 pC will be reported.

II. EXPERIMENTAL SETUP

Femtosecond electron bunches were generated by the photocathode-based linac, which consists of a 1.6-cell S-band radio frequency (RF) gun with a copper cathode, a 2-m-long traveling-wave linac, and an arc-type magnetic bunch compressor. The photocathode of RF gun was excited by UV pulses (262 nm) of a picosecond laser with an energy of <180 μJ/pulse and a pulse width of 5 ps FWHM at 10 Hz. The electron bunches generated in the gun were accelerated in the linac using a 35-MW klystron at a repetition rate of 10 Hz. In the linac, the electron bunches were accelerated to 32 MeV at a linac phase of 100° for an optimal energy modulation of electron bunches [10]. The accelerated electron bunches were compressed to femtosecond by the magnetic bunch compressor, which was composed of bending magnets, quadrupole magnets, and sextupole magnets. CTR was generated by the compressed electron bunch with charge of 170 pC and measured by the large-aperture PCA [9].

Schematic diagram of THz detection using the PCA and measurement system of CTR were shown in Fig. 1. Simplified azimuthal cross section of the PCA [9] was shown in Fig. 1(a). Concentric micro-structured electrodes and photomasks were fabricated on semi-insulating GaAs. A radially polarized THz pulse, i.e., THz electric field in the direction of r, will be introduced to the electrodes of the PCA from the direction of plane GaAs side (z>0). Output of electric-field-induced current due to CTR, which is radially polarized THz pulse, will be obtained by photo-induced charge carriers from the electrodes only when the laser pulse irradiate on the PCA from the electrode/photomask side (z<0). The energy of laser pulses was set to 21 μJ/pulse (800 nm, <130 fs FWHM, Tsunami with Spitfire, Spectra-Physics). Photomasks shield every other gap between electrodes from laser irradiation and enable effective detection of THz pulses. The PCA had THz detection area with diameter of 9 mm [9], where periodic electrode/photomask was fabricated. The PCA was set for the measurement of CTR as shown in Fig. 1(b). CTR was generated at an interface of aluminum mirror using the electron beam of 32 MeV. Collimated THz pulses of CTR were directly introduced to the large-aperture PCA from the plane GaAs side without using focusing lens like a silicon lens. The PCA was irradiated by femtosecond laser pulses from electrode/photomask side. The time delay of the laser pulses was adjusted by a delay line. Electric field strength of THz pulses can be converted to the electric-field-induced current when laser pulses are irradiated on the PCA. Therefore, electric field profile of CTR was obtained as a dependence of the current from the PCA on the time delay.

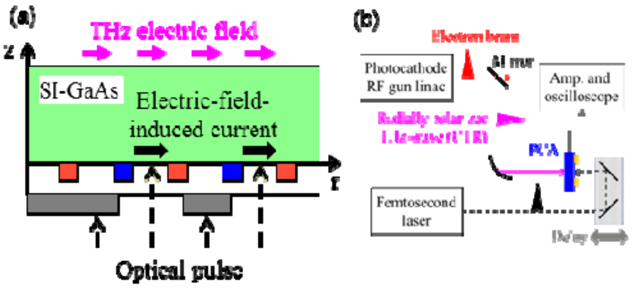

Fig. 1. (a) Schematic diagram of THz detection using the PCA. (b) Measurement system of CTR

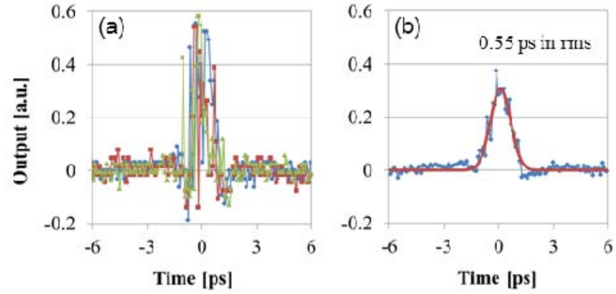

Fig. 2. Temporal electric field profiles of (a) three sequential sweeps and (b) averaged data using twelve sweeps.

III. RESULTS AND DISCUSSIONS

Figure 2 shows temporal electric field profiles of CTR using the PCA. THz electric field of CTR gave an increase in electric-field-induced current only when the laser pulse was irradiated on the electrodes. Three single sequence scans were shown in Fig. 2(a). Instabilities can be observed near the peak of electric-field-induced current due to single-shot measurement for each point. However, averaged electric-field-induced current indicated electric field profile with a Gaussian pulse shape as shown in Fig. 2(b). The averaged profile was calculated using twelve sweeps. According to the fitting result, the bunch length of the averaged profile was 0.55 ps in rms. Current output from a PCA is considered to be proportional to the detected electric field [11]. On the other hand, electric field strength of coherent radiation is supposed to be proportional to electron bunch charge according to an analytical calculation [12]. In the future, precise synchronization between stabilized electron beams and optical pulses would realize broadband detection using ultrashort optical pulses of the order on 10 fs [13].

IV. CONCLUSION

In conclusion, the measurement of CTR using the large-aperture PCA was demonstrated by time-domain scheme. The longitudinal electric field profiles of CTR generated by an electron bunch of 0.55 ps in rms were measured as the electric-field-induced current of the PCA with an irradiation of the femtosecond laser pulses.

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