DEVELOPMENT OF A HIGH-POWER THZ-TDS SYSTEM ON THE BASIS OF A COMPACT ELECTRON LINAC

M. Kumaki#, K. Sakaue, M. Washio, RISE, Waseda University, Tokyo, JAPAN,
R. Kuroda, H. Toyokawa, K.Yamada, AIST, Ibaraki, JAPAN.

Abstract

The high-power terahertz time-domain spectroscopy (THz-TDS) system has been developed on the basis of a compact S-band electron linac at AIST, Japan. The linac whose injector is a photocathode rf gun generates about a 40 MeV, 1 nC electron bunch. The bunch is compressed into less than 1ps with a magnetic compressor. It is bended by a 90-degree bending magnet, which causes generation of the THz coherent synchrotron radiation (CSR). It has useful characteristics such as high power, a short pulse and continuous spectrum. In particular, peak power of THz-CSR is estimated to be about 10^6 times larger than that of the conventional THz source on the basis of the mode-locked fs laser. The THz-TDS is based on the EO sampling methods with the pump-probe technique. The frequency spectrum is obtained by Fourier transform of the measured temporal THz waveform. In addition, it is applied to the ultra-short bunch length monitor by analysing the THz spectrum. In this paper, we will describe details of our system and preliminary experimental results.

INTRODUCTION

The THz light is an electromagnetic wave whose frequency is located in 0.1-10 THz region. In the security field, it is a strong tool for inspection of explosives and banned drugs because they have fingerprint spectrum in the THz region [1]. However, conventional laser-driven THz sources are still low-power sources to use in industrial fields. On the other hand, THz sources based on accelerators can generate a high-power THz pulse.

We have developed generation of high-power THz coherent synchrotron radiation (THz-CSR) at AIST. The synchrotron radiation is emitted coherently when the electron bunch length is shorter than its wavelength.

Figure 1: Schematic diagrams of incoherent (left) and coherent SR (right).

This total intensity ($I_{tot}(\omega)$) including CSR and Incoherent SR intensity ($I_{inc}(\omega)$) is expressed by the following formula,

$$I_{tot}(\omega) = (1 + (N-1)f(\omega))I_{inc}(\omega) \tag{1}$$

N is the electron number in a bunch and $f(\omega)$ is known as the bunch form factor. When the form is assumed to be Gaussian distribution, it is derived from

$$f(\omega) = e^{-\frac{(\omega\sigma_z)^2}{2}} \tag{2}$$

Here, σ_z is the electron bunch length. Figure 2 shows calculation results about the enhancement factor of CSR intensity as a function of its frequency with the 1nC, 30MeV electron bunch [2]. As a result, it is required for THz-CSR generation that the electron bunch length is shorter than 1 ps. When the bunch length is enough short, $f(\omega)$ comes up to 1. It is estimated that CSR intensity is N (10^9~10^{10}) times larger than incoherent SR intensity.

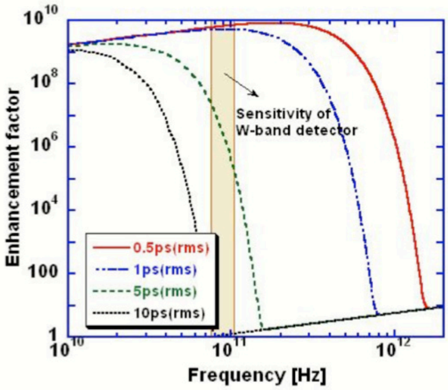

Figure 2: Enhancement factor of CSR as a function of its frequency at each bunch length.

S-BAND LINAC BEAM LINE

The S-band Linac consists of Cs2Te photocathode rf-gun & two S-band (2856MHz) acceleration tubes. Figure 3 shows the layout of its beam line at AIST.

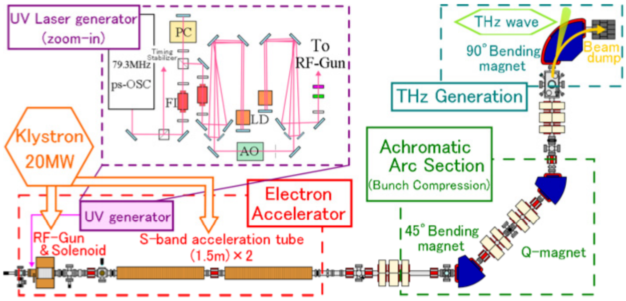

Figure 3: S-band linac beam line at AIST, Japan.

The injector is a BNL-type photocathode rf-gun, which generates 1nC/bunch, 5MeV electron beam. The acceleration tubes accelerate the electron beam up to about 35MeV and the electron beam gets the linear energy chirp by adjusting rf phase at the acceleration tubes. The head and tail of the bunch correspond high-energy and low-energy parts, respectively.

The achromatic arc section is located downstream from the accelerator tubes for the bunch compression. This section consists of two 45-degree bending magnets and four Q-magnets (Fig. 4).

[#] E mail address: rogus@asagi.waseda.jp

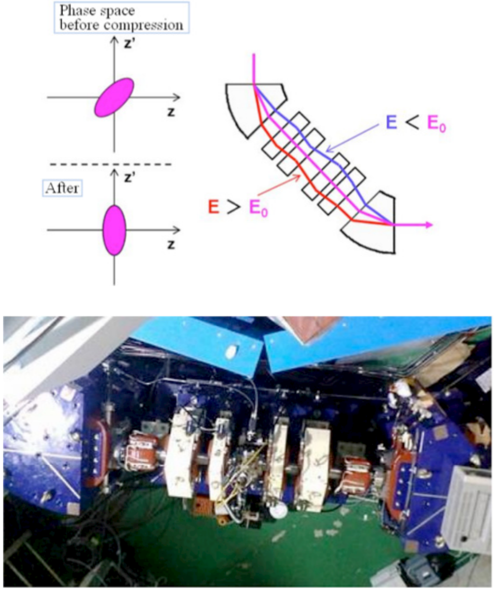

Figure 4: Achromatic arc section.

The achromatic arc section separates the electron orbits into many paths according to the energy. The high-energy and low-energy electrons pass along the long path and the short path, respectively by changing magnetic fields of Q-magnets for the bunch compression. At this section, the electron bunch length is compressed into less than 1 ps from 3 ps for THz-CSR generation [2].

The electron bunch is bended by 90-degree bending magnet and generates the THz-CSR which is extracted at 20-degree point of the magnet. The electron beam parameters are described in Table 1.

Table 1: The Electron Beam Parameters

Energy	35 MeV
Energy spread	< 5 %
Bunch length	< 1 ps
Charge per bunch	1 nC
Rep. rate	10 Hz
Beam size	1 mm × 1 mm

THZ SCANNING IMAGING (ADHESIVE BOND)

The THz transmission-imaging of adhesives in the atmosphere was performed to observe its solidification of adhesives in THz region. The THz-CSR is extracted to the atmosphere from the vacuum through a quartz window and detected with rf detectors (Table 2) which has a centre frequency with a few bandwidth in the THz region (Fig. 5).

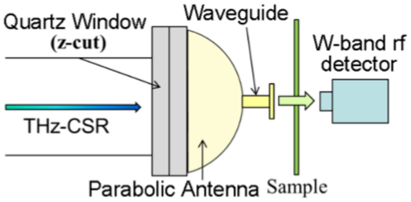

Figure 5: The setup of THz scanning imaging.

Table 2: Specifications of RF Detectors

	Wise Wave FAS-10SF-01	Virginia Diodes, Inc. WR-3.4ZBD
Aperture [mm]	1(H)×2(V)	1(H)×1(V)
Frequency [THz]	0.075~0.11	0.22~0.33
Sensitive [mV/mW]	500	1500

In this experiment, the imaging sample is an adhesive as a kind of the organic polymer. The adhesive is put between polypropylene plates because it is necessary to keep this thickness due to its liquid state at the beginning of this experiment. This sample is illustrated in Fig. 6. The sample is attached to the X-Y stage and scanned with 1 mm/step.

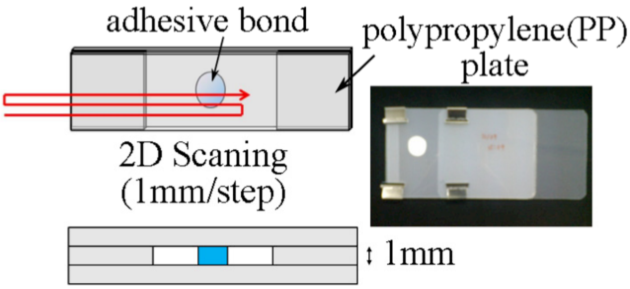

Figure 6: The adhesive bond sample.

Regarding the samples, two kinds of adhesives are selected due to their characteristics. The sample #1 is liquid mixture of polyvinyl acetate (40%) + water(60%) and the sample #2 is cyanoacrylate. Figures 7 and 8 are the results of THz transmission imaging of them.

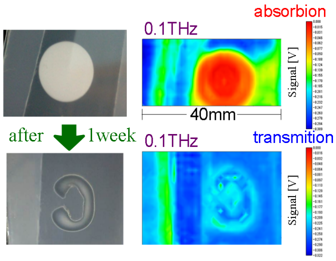

Figure 7: THz imaging result of sample #1 (polyvinyl acetate (40%) + water (60%).

As a result, it is clearly found that the solidification of the polyvinyl acetate was successfully observed in THz region in Fig. 7. The sample #1 became the solid state as its element of water evaporated.

The sample #2 is cyanoacryrlate and well known as the instant glue. When it is in atmosphere, it finishes its solidification process instantly due to the polymerisation by the catalysis reaction of the water vapour. However, it is difficult to bond the glue with PP plates because the PP has no functional group against the cyanoacrylate. However, a part of the glue around its outline vaporizes and contaminates the surface of the PP plate with some dusts. Consequently, both of liquid and solid states exist at the same time.

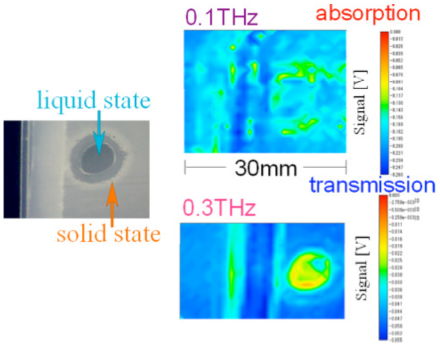

Figure 8: THz imaging result of sample #2 (cyanoacrylate).

As a result, the solid-state glue absorbs the 0.1 THz wave, but it is transmitted by the 0.3 THz wave in Fig. 8. It strongly suggests that the glue has different spectra in the THz region depending on the solid and the liquid state.

THZ-TDS SYSTEM

THz-TDS Based on Laser System

The THz frequency spectrum is obtained by Fourier transform of the THz temporal waveform measured by THz-TDS. As a preliminary experiment, the temporal waveform has been measured by the conventional THz-TDS based on the fs-laser with LT-GaAs photoconductive antennas. The 50 fs, 800 nm Ti:Sa mode-locked laser can drive it as both THz emitter and detector The system is illustrated in Fig. 9. This system is a kind of pump-probe technique. In case of the THz detector, the pump light is the fs laser and the probe light is the THz pulse because THz electric fields accelerate photocarrieer when the fs laser pumps the antenna.

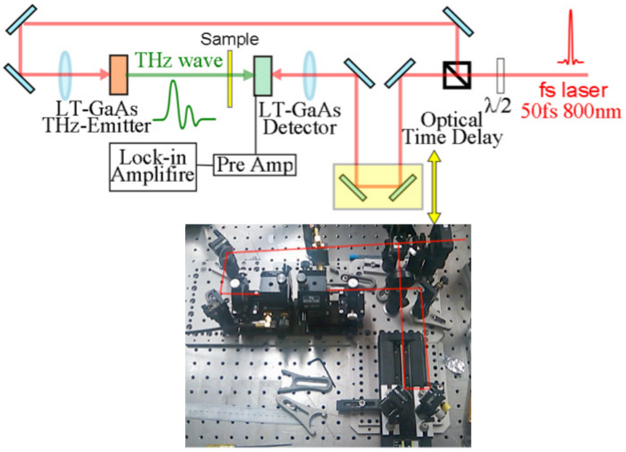

Figure 9: Laser-driven THz-TDS system.

Fig. 10 shows measurement results of the temporal THz waveform and spectrum by Fourier transform of it. The optical delay stage is moved with 5 μm/step. The theoretical pulse length of the THz wave emitted form the antenna using the 50 fs laser is expected to be about 1 ps. However, according to the experimental result, it is expanded to more than few ps because the value of the grope velocity dispersion (GVD) of the polarizing beam splitter (PBS) cube is supposed to be higher than few ps.

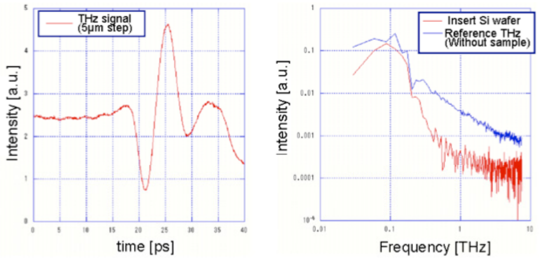

Figure 10: Temporal waveform (left) and spectrum (right) measured by the laser-driven THz-TDS system.

THz-TDS Based on Accelerator System with EO Sampling Method

The THz electric fields cause a complex refractive index of the crystal to change by the electro-optical effect (the Pockels effect). It changes the polarization of the laser when the laser and the THz pulse pass through the crystal at the same time. The EO sampling method is applied to measure the temporal waveform by detecting the polarization difference with the two photodiodes. We have developed this system described in Fig. 11.

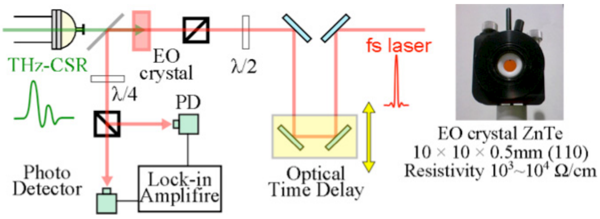

Figure 11: EO sampling THz-TDS system based on the accelerator system (under development).

CONCLUSIONS

The high-power THz CSR generation and scanning imaging of adhesives have been successfully performed with the S-band linac at AIST. As a result, it is clearly observed that the absorption difference of the sample #2 between 0.1 and 0.3 THz. As a preliminary experiment, the conventional laser-driven THz-TDS has been built and demonstrated for measuring the THz pulse. The high power THz-TDS based on the accelerator system has been also developed to obtain the THz spectrum. In near future, the investigation of the un-researched materials will be started with this high-power THz-TDS system.

REFERENCES

[1] K. Kawase et al., Opt. Exp. 11 (20), 2549-2554 (2003)
[2] R. Kuroda et al., Infra. Phys. Tech. 51 390-393 (2008)