SINGLE PICOSECOND THz PULSE EXTRACTION FROM THE FEL MACROPULSE USING A LASER ACTIVATING SEMICONDUCTOR REFLECTIVE SWITCH

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Abstract

The THz-FEL at the Institute of Scientific and Industrial Research (ISIR), Osaka University can generate high-intensity THz pulses or FEL macropulses, which comprise approximately 100 micropulses at 37 ns intervals in the 27 MHz mode or 400 micropulses at 9.2 ns intervals in the 108 MHz mode. The maximum macropulse energy in the 27 MHz mode reaches 26 mJ at a frequency of 4.5 THz and the micropulse energy is estimated to be 0.2 mJ. To open new areas of studies with high intensity THz radiation for user experiments, we are developing a single pulse extraction system from the pulse train using a laser activating semiconductor reflective switch. We have succeeded in extracting a single THz pulse, duration of which is estimated to be less than 20 ps, from the FEL macropulse using a gallium arsenide wafer for the switch.

INTRODUCTION

THz radiation sources recently have been demanded from various scientific and industrial fields [1]. Although there is some THz source, the FEL-based THz radiation source has a great advantage comparing with the other types of source. The remarkable aspects of the THz-FEL are its peak intensity and narrowness of the bandwidth.

The THz-FEL at the ISIR is an oscillator type FEL driven by an rf-linac. Thus, the generated FEL forms a pulse train (macropulse). The macropulse consists of a number of THz micropulses. The micropulse duration is typically similar to the electron bunch duration, thus that duration is about 20 ps in ours. In our case, we have two types of the linac operation for the FEL experiment. The first type of the operation is the dc-beam extraction from the electron-gun and pulsing by the rf-cavity with the frequency of 108 MHz. In this case, the FEL macropulse consists of approximately 400 micropulses with the separation of 9.2 ns. The second type is the pulsed-beam extraction from the gun using the grid-pulser electric circuits with the repetition frequency of 27 MHz. In this case, the FEL macropulse consists of approximately 100 pulses with the separation of 37 ns. In the latter case, we achieved the macropulse energy of 26 mJ at the radiation frequency of 4.5 THz. The maximum micropulse energy is estimated to be over 200 μJ [2, 3].

There are requirements to extract a single micropulse for the investigations of the nonlinear response of materials in order to avoid thermal effects due to the irradiation of the pulse train. To meet these requirements, we are developing the single pulse extraction using a laser activating semiconductor reflective switch, which is also referred as a plasma mirror [4 - 9].

Generally non-doped semiconductors are insulators and thus they have a high transmittance for the radiation in the THz range. Because the THz-FEL radiation is linearly polarized, we can quench the reflecting radiation from the surface of a semiconductor wafer by setting the incident angle to Brewster's angle. Using an intense infrared laser pulse with the photon energy above the band gap energy and irradiating it on the semiconductor wafer, electron-hole plasma is generated on the surface and it becomes a high reflector for the THz radiation. After the diffusion and recombination of the excited electrons, it returns the insulator with a high transmittance. Therefore, we can apply this mechanism into the reflective switching technique to extract a single THz-pulse. The schematic diagram of this mechanism is shown in Fig. 1.

In this paper, we report the overview and present status of the single THz pulse extraction in our FEL facility.

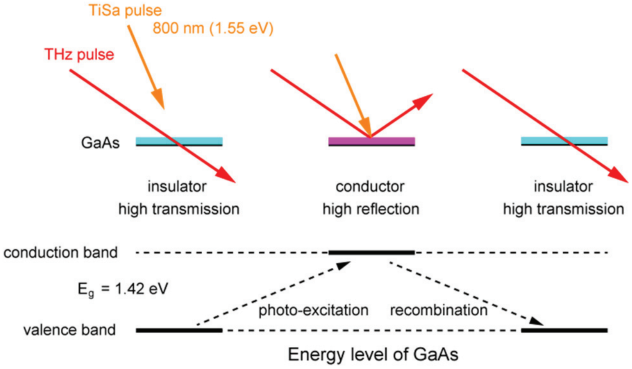

Figure 1: Schematic diagram of the laser activating semiconductor reflective switching for the THz pulse.

EXPERIMENTAL SETUP

The experiment is done using the L-band linac and THz-FEL system at the ISIR, Osaka University [3]. A schematic diagram of the L-band linac and FEL system is shown in Fig. 2. The generated THz-FEL pulses are transported through the vacuum duct to the outside of the radiation shielding area. To activate the semiconductor reflective switch, we use a mode-locked Ti:Sapphire laser system (Spit Fire, Spectra-Physics). The pulse repetition rate of the laser system is 960 Hz and the pulse energy is about 1 mJ. The pulse duration is typically 100 fs and the wavelength is centered at 800 nm. The pulse timing is synchronized to the rf of the linac system. The laser system is placed just beside the user area for the THz-FEL as shown in Fig. 2.

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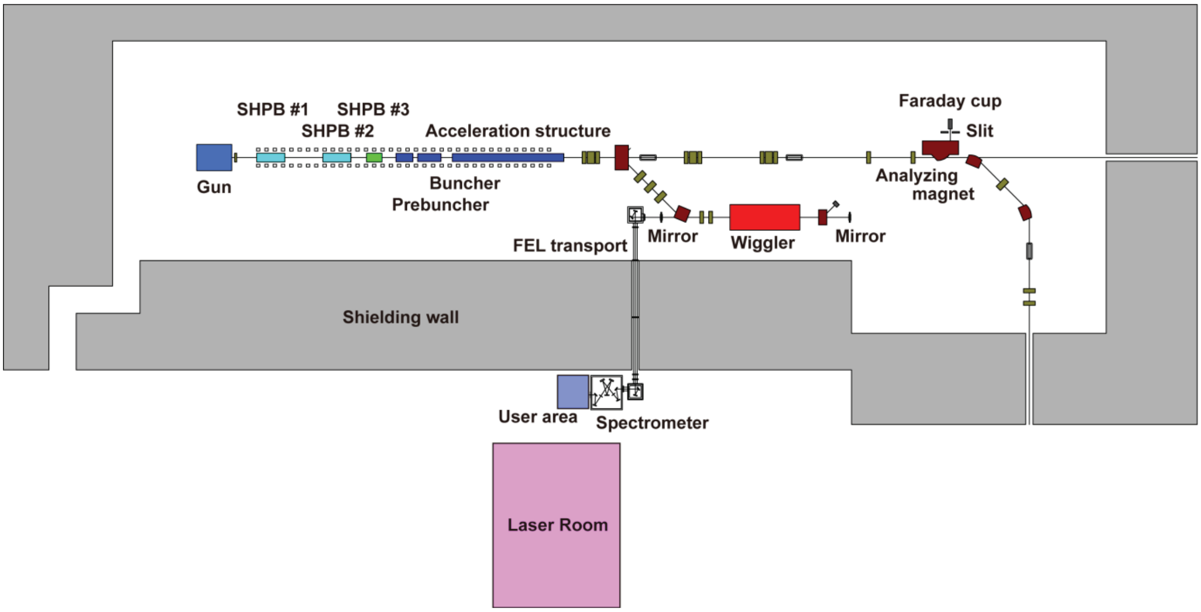

Figure 2: Schematic diagram of the L-band electron linac and THz-FEL. The linac and FEL system are installed inside the restricted room surrounded by the shielding wall. The generated THz-FEL beam is transported to the user area at the outside of the restricted room. The laser room is just beside the user area.

The experimental setup at the user area is shown in Fig. 3. The FEL transverse size at the output of the transport is about 20 mm in diameter. The Brewster's angle of the GaAs at the THz range is about 75 degrees. Thus, the beam size of the THz-FEL beam is needed as small as possible with the small divergence. Using a pair of off-axis parabola mirrors (focal lengths of 3 inches and 0.5 inches), the THz beam is down-collimated with the diameter of about 3 mm. The transmitted and reflected THz-FEL pulse is detected by a calibrated energy sensor (Coherent Inc. J-10), pyroelectric sensor (Molectron, P-5), or diode sensor (Quasi Optical Detector, Virginia Diode Inc.). The Ti:Sapphire laser pulse is transported with an optical delay. To control the irradiance, a half waveplate and polarized beam splitter cube is installed in front of the semiconductor wafer.

As the samples for the switching material, we use a non-doped GaAs wafer and two non-doped Si wafers with the resistivities of 1,000 Ω cm and 10,000 Ω cm. Each wafer has a thickness of 500 μm and a diameter of 2 inches.

RESULTS

As the results of using a GaAs wafer for the switching material and adjusting the laser irradiation timing, we succeed the single THz pulse extraction. The waveforms of the reflected THz radiation detected by the pyroelectric sensor are shown in Fig. 4. On the other hand, in case of using a Si wafer, there are a few reflected pulses after the switching timing. Comparing with the GaAs, Si has a long life-time of the electron-hole plasma [6]. The results shown in Fig. 4 are consistent with that.

To estimate the macropulse contrast which is the ratio between the net switched pulse energy and the total residual reflected energy, we measure the reflected macropulse energy with and without switching. At the radiation frequency of 4.5 THz, the net switched pulse energy is 4.4 ± 0.5 μJ and the macropulse contrast is 2.0.

The reflectance of the switch is estimated from the transmission waveform shown in Fig. 5. Ignoring the absorption of the THz radiation by the GaAs wafer, the reflectance is estimated to be 0.6 ± 0.1.

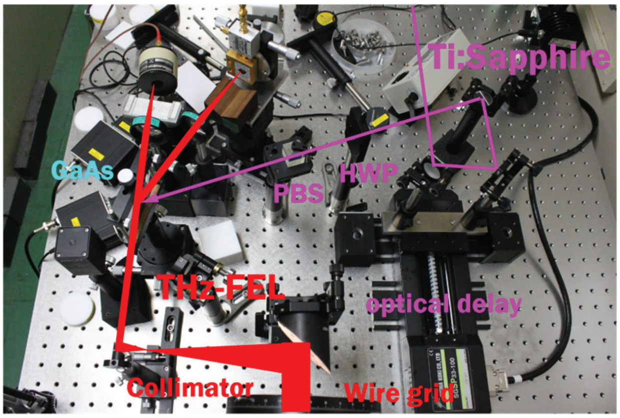

Figure 3: Experimental setup at the user area. The THz-FEL is collimated by using a pair of off-axis parabola mirrors and incident on the semiconductor wafer (GaAs) at the Brewster's angle. Ti:Sapphire laser pulse is transported through the optical delay (two right-angle mirrors mounted on the linear stage), half-waveplate (HWP) and polarized beam splitter cube (PBS).

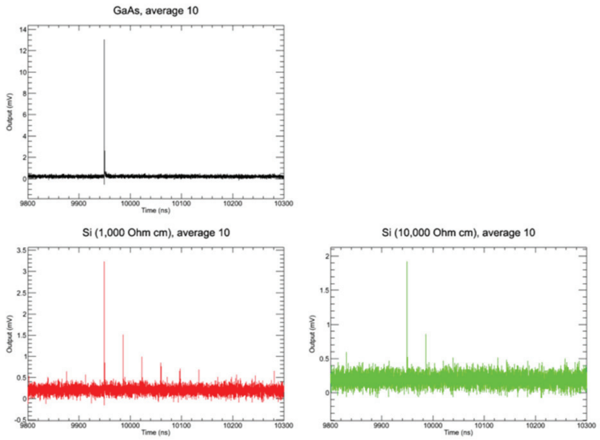

Figure 4: Waveforms of the reflected THz-pulse(s) by the pyroelectric sensor. In case of GaAs, only one pulse is observed in the linear scale. On the other hand, in Si cases, a few pulses are observed.

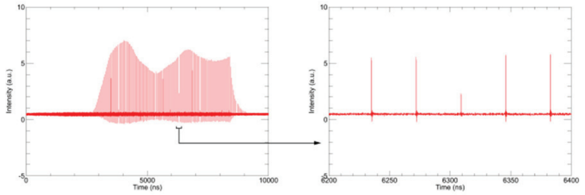

Figure 5: Waveform of the transmitted THz-pulses. Left side is a whole macropulse and right side is enlarged around the switching timing.

CONCLUSION

By using the Ti:Sapphire laser and the GaAs wafer as the reflective switching material, we succeed the single THz-pulse extraction from the FEL macropulse. As the present results, the extracted pulse energy is 4.4 µJ at the radiation frequency of 4.5 THz and the macropulse contrast is 2. Optimization of the single pulse extraction is continuing.

High intense single THz pulse beam is useful for various applications to investigate the materials science and other fields. We will make intense single THz pulse source based on the FEL and the laser activating reflective switching technique in near future.

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