INTENSE THz RADIATION GENERATION FROM A COMPACT ELECTRON LINAC*

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Abstract

A femto-second THz radiation (FS-THz) facility is under commissioning at the Pohang Accelerator Laboratory (PAL), which uses a 70-MeV electron linac consisting of an S-band photocathode RF gun with 1.6 cell cavity, two S-band accelerating structures, and two chicane-type bunch compressors. The linac is designed to generate THz pulse with energy up to 10 μJ by transition radiation from a metal target hit by sub-picosecond electron beam. The linac takes advantage of the advanced technologies such as an inverter-type klystron modulator with stability below 100 ppm and a high precision synchronization system between laser and RF. The THz radiation intensity measured with a Golay cell is 0.75 μJ/pulse from the 0.5 nC electron beam. We will present the commissioning results of THz radiation generation.

INTRODUCTION

PAL is constructing a femto-second THz radiation facility that is designed to generate THz radiation with the pulse duration of 150 femto-second and the pulse energy of 10 μJ or higher at the repetition rate of 30 Hz. The radiation whose frequency is in the range of 0.3 to 3 THz is coherent transition radiation (CTR) that is emitted from metal target hit by relativistic electron beam with the pulse duration shorter than the radiation wavelength. There has not been a high bright radiation source in the THz region where rich science is unexplored.

THz radiation from sub-picosecond relativistic electron beam is transversely coherent because the emittance of the electron beam is much smaller than the emittance of THz radiation. For example, if the normalized emittance of a 50 MeV beam (relativistic factor 100) is 10 μm-rad, the un-normalized emittance is 10 μm-rad/100, which is much smaller than the emittance of 100 μm wavelength radiation, 100 μm / 4π.

The THz radiation facility consists of a 70-MeV electron linear accelerator to generate relativistic electron beam and a beamline where users will carry out their experiments using THz radiation, and Ti-Sapphire laser system. Figure 1 shows the layout of the FS-THz radiation facility. The electron linear accelerator consists of an S-band photocathode RF gun with 1.6-cell cavity to generate a 5-MeV electron beam by irradiating laser beam onto the cathode surface,

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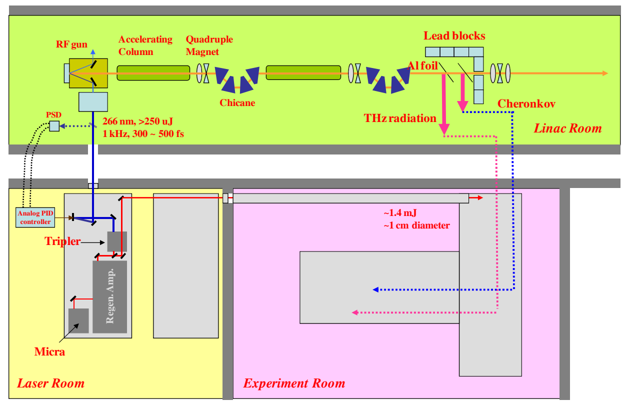

Figure 1: Layout of the FS-THz radiation facility.

two S-band accelerating structures to boost the electron beam energy to 70 MeV, and two chicane-type bunch compressors which comprises of four dipole magnets. To generate intense femto-second THz radiation up to 3 THz, the electron beam with the charge of 0.5 nC should be compressed down to below 150 femto-second.

The laser system consists of a MICRA oscillator and a Coherent regenerating amplifier system that generates 800 nm laser beam with the output power of 3W and the pulse duration of 120 fs at the repetition rate of 1 kHz. A 3rd harmonic generator is used to generate 266 nm / 200 μJ laser beam which is transported to the photo-cathode RF-gun.

The objective of the facility is to support researches for ultra fast science using femto-second THz radiation. Most experiments are expected to be pump-probe experiment that requires high brightness photon beam, very stable photon intensity as well as small time jitter between pump and probe photon beam. For that experiment the THz radiation is used as pump or probe and the visible / infrared radiation from the Ti-Sapphire laser act as the counter part.

One S-band klystron amplifier feeds 50 MW RF power with the pulse length of 2 μs to the S-band accelerators to accelerate the electron beam to 70 MeV. A high voltage pulse modulator that supplies a high voltage pulse signal to klystron has voltage jitter at shots to shots because of pulse characteristics. The time jitter between pump and probe photon beams is caused by both the laser system and the klystron modulator. Jitter between laser oscillator and RF oscillator can be reduced by a timing stabilizer using 9th harmonics of mode lock frequency of laser oscillator,

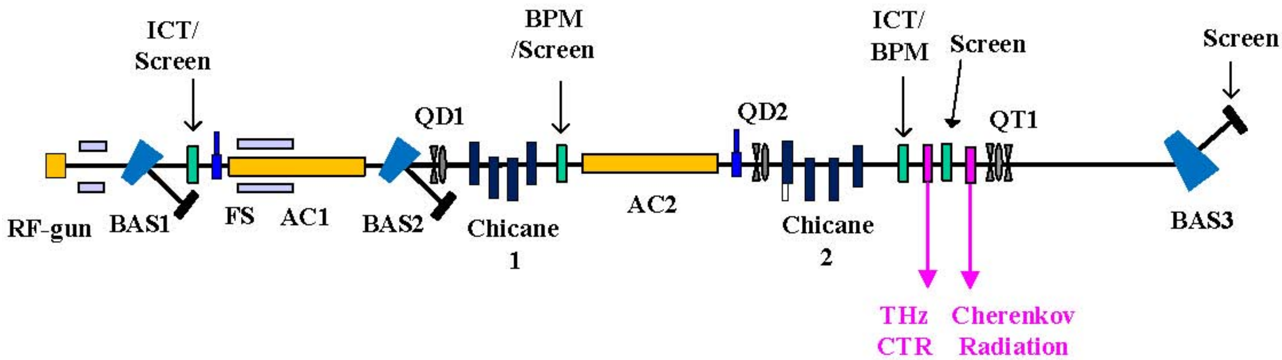

Figure 2: Layout of Linac. (QD: quadrupole doublet, ICT: integrated current transformer, FS: focusing solenoid, AC: accelerating column, QT: quadrupole triplet, OTR: optical transition radiation, BAS: beam energy analyzer, and YAG: YAG screen).

which is incorporated in the laser oscillator. The pulse to pulse voltage jitter of the klystron modulator results in jitters of the amplitude and phase of the RF output of the klystron. The beam dynamics simulation shows that the RF-phase change of 1-degree results in 3 times increase of the electron beam bunch length, which means there should be a big reduction of THz intensity as well as decrease of spectrum bandwidth. Allowing a 20 % increase of the bunch length gives an jitter requirement: RF phase stability with respect to the laser oscillator should be better than 0.1 degree (= 100 fs), which gives the klystron modulator stability requirement of 0.01 % (100 ppm).

Two kinds of radiation using relativistic electron beam will be provided for pump-probe experiments for the beamline: transition radiation for THz radiation (probe) and Cherenkov radiation for visible radiation (pump). Cherenkov visible radiation can eliminate jitter problem because both the THz and Cherenkov radiation are generated by using the same electron beam so that there is no time jitter between them. Transition radiation occurs when an electron crosses the boundary between two different media. The target material is Al foil of 5 μm thickness. When an electron moves with velocity larger than speed of light in a dielectric medium, Cherenkov Radiation (CR) is emitted as a shock wave whose wavefront is no longer spherical like transition radiation. One dimensional wavefront can be regarded as a plane wave. Accordingly, CR is focused onto infinitesimal image by far-field optics in one-dimensional geometrical optics, or equivalently an infinitely thin optical ring in three-dimensional geometrical optics. Fused silica of 100 μm thickness will be used as a dielectric medium.

COMMISSIONING OF THz GENERATION

The installation of the electron linear accelerator was finished in 2008 as well as a high stability pulse modulator and a high stability low-level RF control system, which are the key components necessary to get the bunch length of 150 femto-second. The high voltage pulse modulator for klystron shows a pulse to pulse stability of 133 ppm peak-

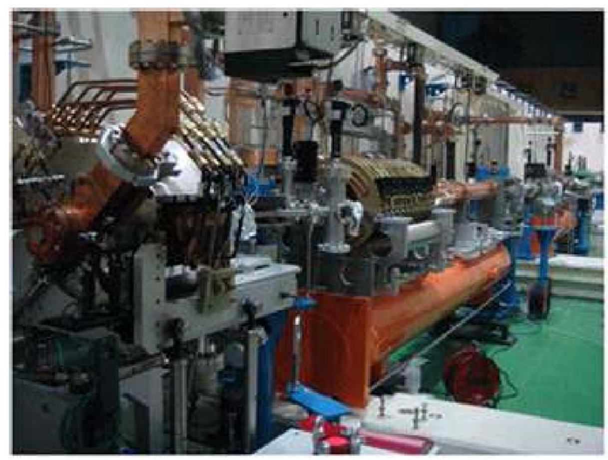

Figure 3: Picture of 70-MeV electron linac.

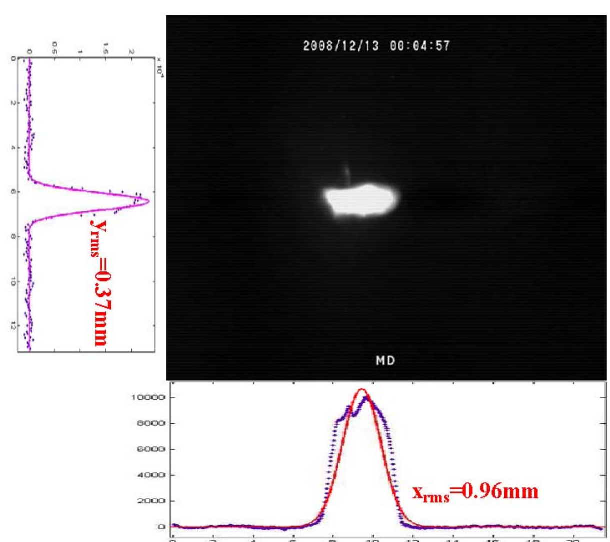

Figure 4: Emittance measurement.

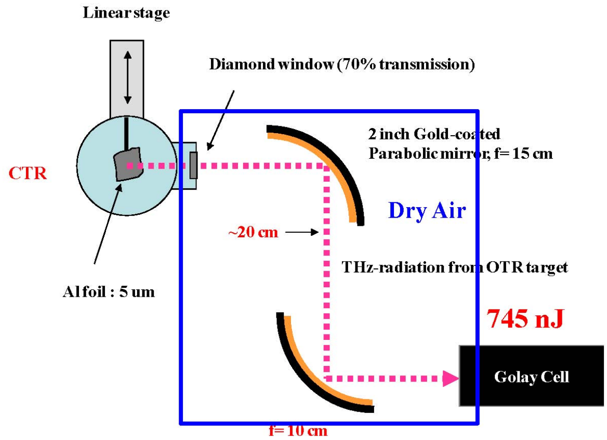

Figure 5: THz measurement setup in CTR target.

to-peak and 45 ppm rms. The electron beam acceleration test was successfully done to achieve the beam energy of 75 MeV. The normalized beam emittance was measured to be 8 μm-rad when the RF-gun energy was 2.5 MeV and the beam energy was 50 MeV, the beam charge was 0.2 nC and the laser pulse length was 500 fs. The relative high beam emittance of 8 μm-rad comes from the space-charge force due to the small RF-gun energy and short laser pulse length.

The optical transition radiation in visible range was measured by hitting a 50-MeV electron beam to the metal target in the OTR chamber located downstream the second Chicane. The CTR chamber which is located beside the OTR chamber has a diamond window with the THz transmission of 70 %. Generation of THz radiation was successfully done to get 0.75 μJ/pulse, which was measured at the CTR chamber. A gold-coated parabolic mirror of 2 inch diameter, a Golay Cell and a lock-in amplifier are used in the measurement (see Fig. 5). The humidity in the accelerator tunnel was about 28 %, therefore, the absorption coefficient of the air is estimated to be about 0.05 cm^{-1} so that the attenuation of THz radiation is estimated to be 90 % in the flight distance of 50 cm from the diamond window to the Golay Cell. Correcting for the attenuation, the THz intensity is 7.5 μJ/pulse at the outside of the dimond window.

It is confirmed that the radiation is coherently enhanced by reducing the electron bunch length to shorter than the THz radiation wavelength from the fact the measured intensity of incoherent radiation measured at the chicane magnet field of 0 Tesla is as small as 0.00006 μJ/pulse as shown in Fig. 6. The intensity enhancement from incoherent to coherent is done by turning-on the chicane-type bunch compressor to reduce the bunch length of electron beam shorter than the radiation wavelengths. The dramatic enhancement of intensity of coherent radiation was observed in the measurement.

Figure 7 shows the improvement of RF-gun temperature stability from 1 °C to 0.1 °C. After this improvement the THz intensity variation reduced from 20 % to 2 %. It turned out that the cavity temperature change of 1 °C causes a RF-gun's RF phase change of 8 degrees. The factors to determine THz intensity stability are the stability of bunch length, bunch charge, electron beam energy and the beam position stability on the CTR target. The 2 % stability, which is resulting from the stability of all systems such as the stability of klystron modulator and RF, a small jitter between laser and RF, the cavity temperature stability, and the laser energy stability, is acceptable for the beamline experiments.

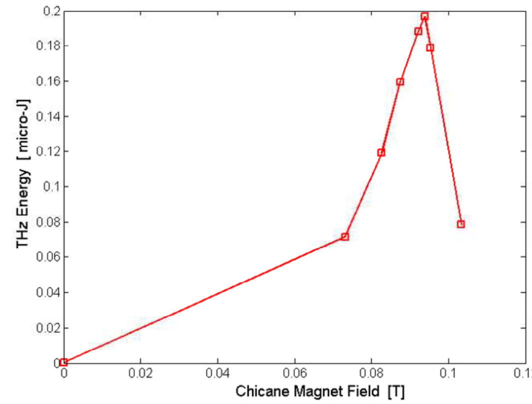

Figure 6: THz pulse energy as a function of chicane magnetic field.

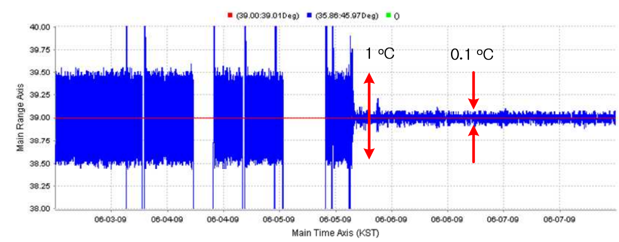

Figure 7: Improvement of RF-gun temperature stability.

SUMMARY

Commissioning of THz generation is being carried out using a 75 MeV compact electron linac at Pohang Accelerator Laboratory. The THz radiation intensity measured with a Golay cell is 0.75 μJ/pulse with a fluctuation of 2 % from the 0.5 nC electron beam. Correcting for the attenuation, the THz intensity is 7.5 μJ/pulse at the outside of the dimond window. The small variation of THz intensity of 2 % results from the stability of all systems such as the stability of klystron modulator and RF, a small jitter between laser and RF, the cavity temperature stability, and the laser energy stability.

REFERENCES

[1] H.S. Kang, et al., WEPPH032 in Proceedings of FEL 2007, Novosibirsk, Russia, p. 421, www.JACoW.org.