ELECTRON BUNCH LENGTH MEASUREMENT USING COHERENT RADIATION SOURCE OF fs-THz ACCELERATOR AT POHANG ACCELERATOR LABORATORY

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Abstract

A Michelson interferometer was installed at the femtosecond (fs) terahertz (THz) Accelerator of Pohang Accelerator Laboratory(PAL) to measure a subpicosecond order electron bunch length. To measure an ultra-short electron bunch length, we use reconstruction process and fast fourier transform. Currently, we are generating THz radiation with the pulse energy of 7μJ by means of coherent transition radiation (CTR) from a 65-MeV electron beam of the fs-THz accelerator. In this paper, we show the how to make a longitudinal distribution of electron bunch and the radiation intensity difference between CTR and Coherent edge radiation (CER) for nondestructive electron bunch length measurement. And we report the measurement methods to get the fine electron bunch length information.

INTRODUCTION

A fs-THz accelerator at Pohang Accelerator Laboratory (PAL) was constructed to generate high intensity THz radiation [1-3]. The Fs-THz accelerator consists of a photo-cathode RF-gun, two S-band accelerating structures, and a magnetic bunch compressor. Now, the electron beam with 65-MeV energy, 200pC charge, and 200fs bunch length is generated at the 10-Hz repetition rate, and 7μJ THz pulse is radiated from the electron beam through transition radiation. To obtain THz radiation from this linac, we use a coherent transition radiation (CTR) method. Coherent transition radiation is a combined process of coherent radiation and transition radiation

In the coherent radiation, electron bunch length is the most important factor. There are a few electron bunch length measurement methods, for example, Streak camera, Michelson interferometer method and others[4,5]. Streak camera can't measure under 200fs. Since our experiment is aiming at sub 200fs bunch length, we use Michelson interferometer method to measure the bunch length.

The manuscript is organized as follows. In section II, we discuss about Michelson Interferometer and how to make an interferogram and longitudinal bunch distribution. In section III, we present the results of electron bunch length measurement and discuss them in detail.

CTR AND MICHELSON INTERFEROMETER METHOD

The Michelson interferometer consists of three mirrors and two beam splitters. Among them, two mirrors are focusing mirrors and another one is a plate moving mirror (see Fig. 1). The radiation going through the interferometer is split by a beam splitter and it creates a path difference introduced by a moving mirror. These two split radiations are recombined in Golay cell 1.

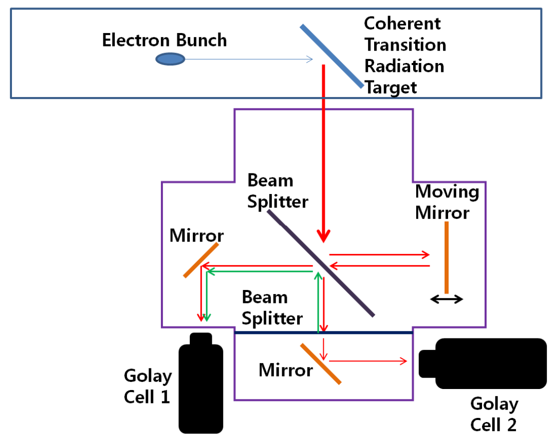

Figure 1: Michelson Interfereometer's setup used in our experiment.

This combined signal is used further to generate an interferogram and longitudinal e-bunch distribution (see Fig. 4 and 5). Another radiation beam coming from the second beam splitter is detected by Golay cell 2, which is used as reference radiation for feedback system. Using these steps, we can measure the electron bunch length. The measured bunch length is of the order of 200 fs (FWHM).

EXPERIMENTAL RESULTS AND THZ COHERENT RADIATION

Electron bunch length measurement experiment is carried out at the fs-THz linac tunnel. The schematic view of the fs-THz linac is shown in Fig. 2 (a) and the picture of fs-THz facility is shown in Fig. 2 (b).

This fs-THz linac consists of a photo-cathode RF-gun, two accelerating columns, one chicane, a 1μm thick titanium (Ti) target and quadrupole magnets. The photo-cathode RF-gun generates the electron bunch, two accelerating columns accelerate the electron beam up to 65-MeV energy, and the electron bunch is compressed by chicane. This compressed 65-MeV electron beam generates 7μJ energy of coherent transition radiation when it strikes on Ti target [7]. THz radiation energy of the fs-THz linac measured during the past one year is shown in Fig. 3.

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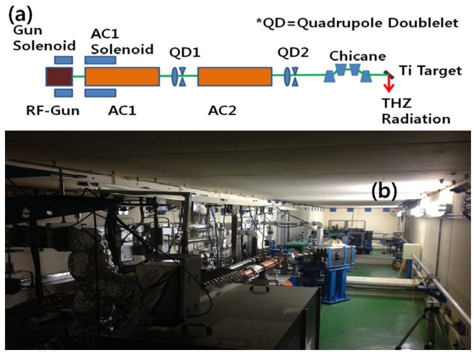

Figure 2: (a) Schematic Layout of the fs-THz linac and (b) a view of the fs-THz linac tunnel.

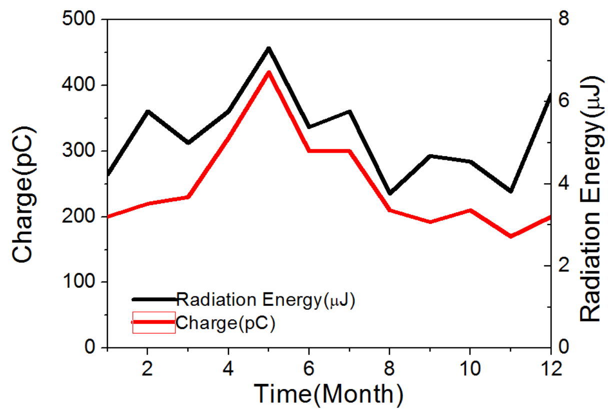

Figure 3: THz radiation energy measured during the past one year.

We take information of the electron bunch by analyzing the output THz radiation. Next to the Ti target, this radiation is sent to the Michelson interferometer setup. By using the interferometer, we get the information of electron bunch's longitudinal distribution. These results are shown in Fig. 4 and Fig. 5.

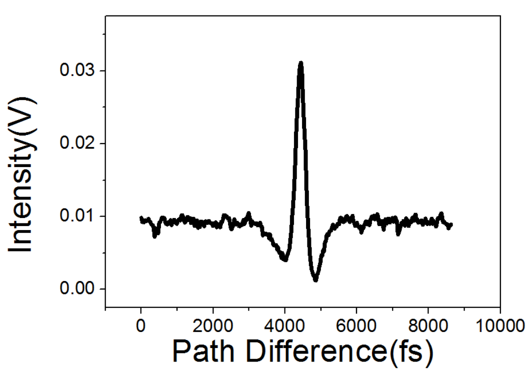

Figure 4: The Interferogram image.

In Michelson interferometer setup which is seen in Fig. 1, CTR radiation is divided into reflected and transmitted radiation by beam splitter. These two radiations' path difference is made by the moving mirror. Transmitted radiation goes to the second beam splitter and reflected by it and goes to golay cell 1. The reflected radiation by moving mirror transmits the first beam splitter and goes to golay cell 1. In golay cell 1, two radiations are combined. This combined radiation's intensity is changed by the moving mirror and the first beam splitter's distance changes. So we can take an interferogram by moving the moving mirror and take a radiation intensity change. To obtain the fine image of interferogram, we need to make a stable base line. The methods for making a stable baseline are dry air injection and a stable RF phase control. Stable RF phase control is related to the temperature stability of the all systems.

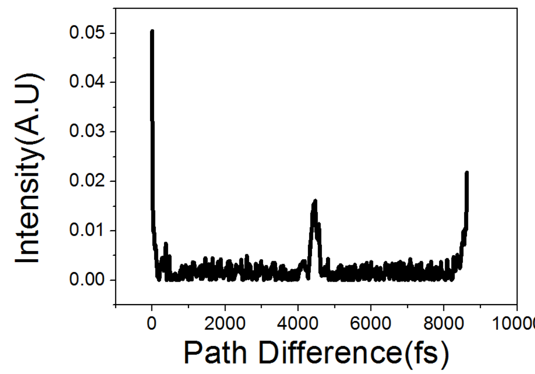

Figure 5: The longitudinal electron bunch distribution.

Figure 4 shows the interferogram results. This interferogram is generated by combining the two radiation intensity obtained from the interferometer's golay cell 1. We move the moving mirror slowly under 1 mm/s and scan the intensity of golay cell 1. Using this interferogram, we can get the longitudinal bunch distribution. Figure 5 shows the longitudinal electron bunch distribution. Firstly, using fast Fourier transform (FFT), we can transform the interferogram to the THz frequency band that is shown in Fig. 8. Next, using the square root of the THz frequency band result and inverse fast Fourier transform (IFFT), we can obtain the longitudinal bunch distribution as shown in Fig. 5. This whole procedure is well explained in [6].

After setting our experiment, we carried out several measurements of the electron bunch lengths using different conditions. From these measurements, we can establish the relation between the radiation intensity and the electron bunch length. The results are shown in Fig. 6. It is shown that the shorter the bunch length is the higher the radiation intensity. In the CTR, coherent radiation is closely related to the bunch form factor. The bunch form factor's critical part is bunch length. So we think that the THz radiation intensity measurement can be used for determining the bunch length as long as the THz radiation intensity measurements are done at the same condition. From Fig. 6, we can deduce the electron bunch length from the radiation intensity for a fixed charge of electron bunch. Using this result, we can take the relation of electron bunch length and THz radiation intensity.

So using this information, we can take the relative electron bunch length by a pulse by pulse THz intensity measurement. In CTR, the electron beam is destructed by

Titanium(Ti) foil. But if we use Coherent edge radiation (CER) source, we can use coherent radiation without destructing the electron beam. CER is edge synchrotron radiation from the last dipole of Chicane measured by a gold coating mirror. CER mirror looks like CTR target but it has a hole in the center. So electron beam is passing through the hole and CER is reflected by the mirror. So we can measure radiation intensity without destruction of the electron beam. Using CER and the data of Fig. 6, we can calculate the shot to shot electron bunch length without destruction of electron beam. The RF phase correlation of CTR and CER is shown in Fig. 7.

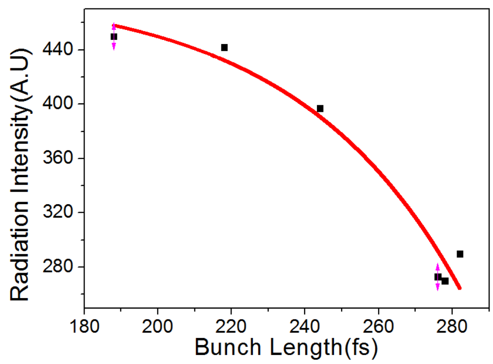

Figure 6: Bunch length versus THz radiation intensity.

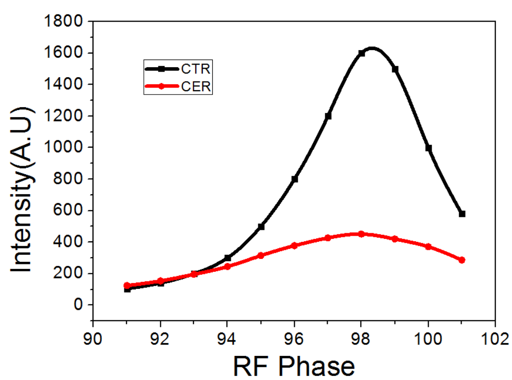

Figure 7: RF phase correlation of CTR and CER.

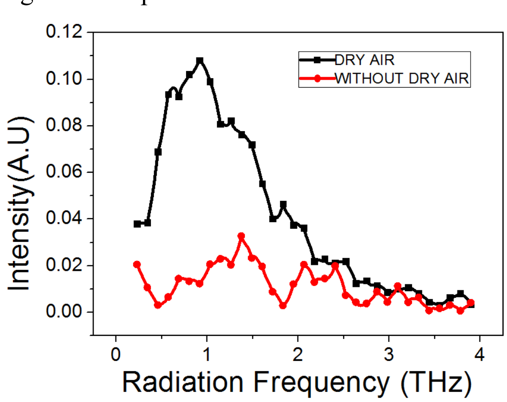

Figure 8: THz band with dry air and without dry air.

THz radiation is easily absorbed by water. In this vein, we check the effect of humidity by using dry air. Figure 8 shows THz frequency bands with dry air and without dry air. In the figure we can see that most of THz radiation between 0 to 2 THz is absorbed by water at no dry air condition. As the water absorbs THz radiation, it may affect the interferogram measurements at baseline.

CONCLUSION

The measurement of electron bunch length at the fs-THz facility was conducted. We measured the 100 femtosecond order bunch length of a 65-MeV electron beam by employing the Michelson interferometer method. The shortest electron bunch length we achieved is 190 fs. Using this measurement result we can calculate electron bunch length and CTR energy's relation. Also using CER's result we can develop a non-destructive electron bunch length measurement method and we need to do another experiment to measure the bunch length at different electron beam energy in order to know the relation between beam energy and bunch length. Our next subject is to use the IR Prism Single shot Method and nondestructive method like CER, and measure electron bunch's transverse information using Pyro Camera.

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