FEMTOSECOND E-BUNCH LENGTH MEASUREMENT AT fs-THz ACCELERATOR AT PAL

Jun Ho Ko , In Soo Ko, POSTECH, Pohang, Korea
Heung-Sik Kang, PAL, Pohang, Korea

Abstract

We have carried out the measurement of electron beam bunch length at the 65-MeV electron linac of Pohang Accelerator Lab. We measure the bunch length using Michelson interferometer. Longitudinal distribution of femto-second electron beam has been evaluated by the coherent transition radiation Michelson interferometer with the reconstruction procedure from interferogram. We use this skill to make a plot of radiation energy and bunch length to show that coherent radiation is emitted from an electron bunch, whose length is shorter than the wave length of the radiation.

INTRODUCTION

The equation for coherent radiation is written as [1]

$$P(\omega) = p(\omega)N[1 + (N - 1)f(\omega)] \qquad (1)$$

, where $P(\omega)$ is total radiation power, $p(\omega)$ is the spectral radiation power from a single electron, $f(\omega)$ is bunch form factor. One can see that if the electron bunch length is shorter than radiation wave length, it can generate a coherent radiation. So we want to confirm the coherent radiation condition from an experiment which is to measure the bunch length and compare it with the radiation energy.

There are many techniques to measure the bunch length such as streak camera, Michelson interferometer, polychromator, and fluctuation method [2, 3]. Each technique has pro and cons. The streak camera is useful for the pulse to pulse (in short ptp) measurement but it can't be used for the bunch length shorter than 200fs or near. The interferometer can be used shorter than 200fs but it can't be used for the ptp measurement and high intensity coherent radiation. The polychromator can be used under 200fs and for the ptp measurement, but it requires high intensity coherent radiation. The fluctuation technique is possible to use the ptp measurement and under 200fs bunch length, but its radiation is incoherent and low intensity.

A 65-MeV electron linac at PAL, whose name is FS-THz linac, can provide the electron beam bunch shorter than 200 fs to generate high intensity, coherent radiation. To measure the bunch length, we need time resolution of below 200fs. Interferometer or polychromator is only available even though the ptp measurement is not possible. We select the Michelson interferometer technique for this measurement. In this paper we introduce the Michelson interferometer method to measure the sub-picosecond electron bunch length. And we make a plot of radiation energy versus bunch length to make sure the coherent radiation is related to the bunch length [4].

EXPERIMENTS AND DISCUSSION

We use the FS-THz linac at Pohang Accelerator Lab. This linac consists of a photo cathode RF-electron gun, two accelerating columns, chicane and transition radiation radiator. The e-bunch reaches 65 MeV through two accelerating columns and hits the foil to generate THz radiation. The THz radiation goes to Michelson interferometer to measure the bunch length. The FS-THz linac at PAL and the interferometer set up is shown in Fig. 1 and 2, and the linac parameters are listed in Table 1.

Figure 1: FS-THz linac at PAL.

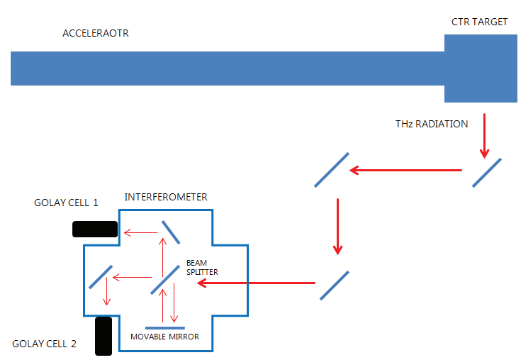

Figure 2: Interferometer measurement set up.

Table 1: PAL THz linac parameters

Parameter	Value
Beam energy	65MeV
Repetition rate	10Hz
Laser pulse energy	30μJ
Electron bunch charge	200pC
Modulator DCHV	38kV
Target	1μm (Ti) foil

The linac generates coherent radiation using Transition radiation. When an electron bunch passes through the two medium it generates radiation which is the Transition radiation. And if the bunch length is shorter than radiation wavelength, the radiation can be coherent radiation. Our experiment uses this concept [5].

The Michelson interferometer can measure electron bunch length using the coherent transition radiation. The radiation generated from transition radiation goes to the Michelson interferometer and we control a mirror in the Michelson interferometer using computer program made by LABVIEW. We can make an interferogram. Using this interferogram and procedure of reconstruction, eventually we can measure the bunch length of the electron beam. According to the previous research, reconstruction procedure is used to obtain the longitudinal bunch form factor by [6],

$$f_L(\nu) = \frac{\int_{-\infty}^{+\infty} S(\sigma) e^{-\frac{i2\pi\sigma\nu}{c}} d\nu}{4\pi c|RT|^2 N^2 I_e(\nu)} \quad (2)$$

, where N is the number of electrons in the bunch and $I_e(\nu)$ is the radiation intensity emitted from a single electron, R is coefficient of reflection, T is coefficient of Transmission, and $S(\sigma)$ is the light intensity of the recombined radiation at the detector, which is related to the interferogram.

And we can obtain another equation of longitudinal bunch form factor:

$$f_L(\nu) = \left|\int_{-\infty}^{+\infty} h(z) \exp(i2\pi\nu z)\, dz\right|^2 \quad (3)$$

, where h(z) is longitudinal bunch distribution. So we can make the longitudinal bunch length from the interferogram. This interferogram result is shown in the Fig. 3. From this result we can get the electron bunch length of 182fs in FWHM.

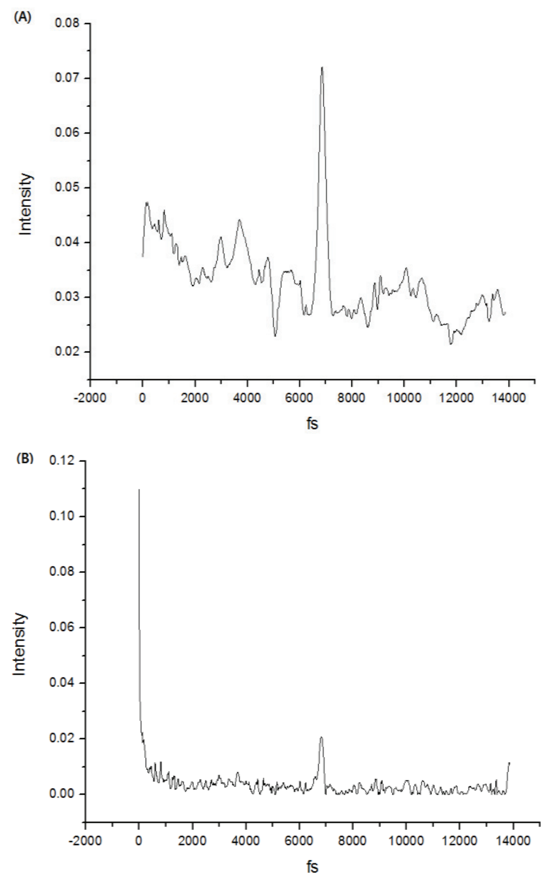

Figure 3: (a) Interferogram, (b) longitudinal distribution of E-bunch

After that, we did another experiment to compare THz radiation energy with E-beam bunch length. For this comparison we should do the experiment with the same laser energy at the photocathode RF Gun to generate the same charge electron beam.

From Eq.(1) the radiation energy depends on number of electrons and E-bunch's longitudinal distribution. If we fix the number of electrons, the radiation energy only depends on the E-bunch longitudinal distribution. This result is shown in the Figure 4.

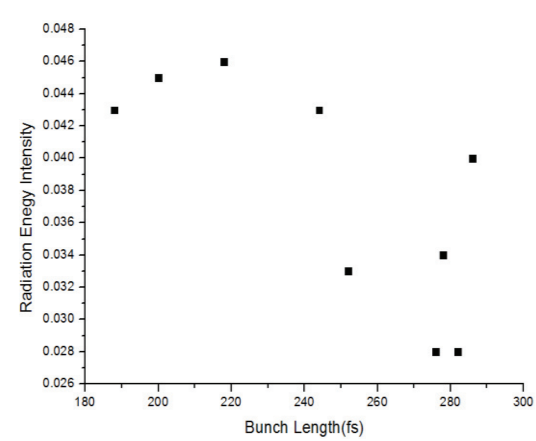

Figure 4: Bunch length versus radiation energy

This result shows that as the bunch length is decreased, the radiation intensity increases and reaches saturation.

And using this data we can get additional information about THz radiation by using Fourier transformation method. It is the relation of THz radiation bandwidth to bunch length and THz radiation intensity, respectively. This result is shown in the Figure 5.

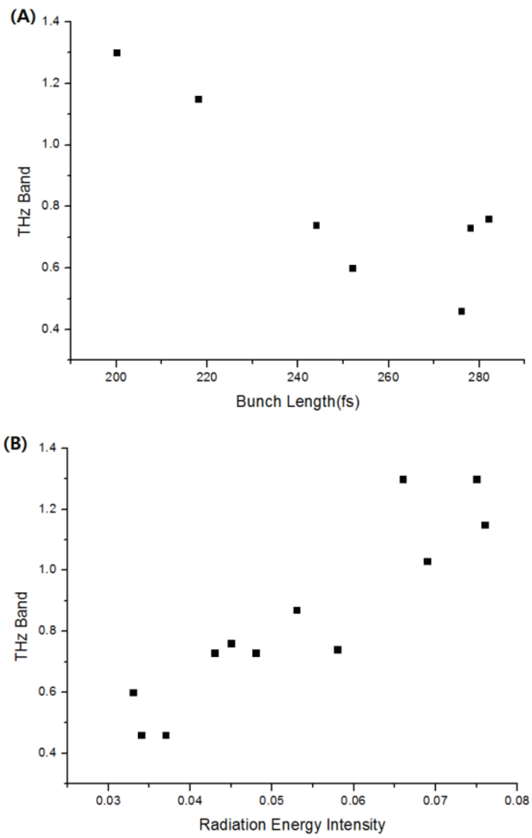

Figure 5: (a) bunch length versus THz bandwidth, (b) radiation intensity versus THz bandwidth

This result shows the THz bandwidth is related to the bunch length, and if we can make bunch length shorter, then we can generate the higher frequency THz radiation.

SUMMARY AND OUTLOOK

We measured the bunch length of sub-picosecond electron beam by using the Michelson interferometer. We can get the bunch length shorter than 200fs and additional information about transition radiation. To get more reliable result, we will use dry air in the interferometer and take a more accurate result of THz radiation bandwidth.

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