ULTRA-SHORT ELECTRON BUNCH GENERATION BY AN ECC RF GUN*

Y. Koshiba†, T. Aoki, M. Mizugaki, K. Sakaue, M. Washio, Waseda University, Tokyo, Japan
T. Takatomi, J. Urakawa, KEK, Ibaraki, Japan

Abstract

Energy Chirping Cell attached rf gun (ECC rf gun) is a photocathode rf gun specialized for ultra-short bunch generation. This ECC rf gun has been made with the collaboration of High Energy Accelerator Research Organization (KEK) [1] [2]. Although the bunch length could be controlled by the laser pulse width, the bunch length ends up to be more than 1 ps due to space charge effect when using a femto-second laser and a normal 1.6 cell cavity. Concerning this phenomenon, ECC is attached right after the 1.6 cell so that the electron bunch would be compressed after the electron bunch is accelerated around 5 MeV. The roll of ECC is to chirp the energy with the linear part of the rf electric field. The electron bunch would be compressed by velocity difference as it drifts. Simulation results from PARMELA and GPT show that the ECC rf gun can accelerate an 100 pC bunch with the bunch length less than 100 fs. We already manufactured this ECC rf gun and installed in our system. We demonstrated the ultra-short bunch by measuring the coherent THz light by synchrotron radiation and transition radiation. In this conference, we will report the results of ultra-short bunch generation experiments, and future plans.

INTRODUCTION

Photocathode RF Gun at Waseda University

We have been developing a photocathode rf electron gun at Waseda University. The cavity structure is based on a BNL TypeIV 1.6 cell cavity and can accelerate electron bunches up to the energy of 5MeV. Photocathode rf gun can generate a high quality electron beam which means low emittance, high brightness, and short pulse. The beam from the gun depends strongly on the laser parameter, so it is able to control the beam's initial behavior by controlling the laser. In our system, the rf frequency is 2856 MHz and the cathode material is Cs-Te. The bunch length is almost the same with the laser pulse width and is about 4 ps (rms) in our system. Some studies are done using this system such as pulse radiolysis experiment for radiation chemical reactions [3], microbeam radiation therapy [4], and soft X-ray generation via laser-Compton scattering [5].

Ultra-short Bunch

Ultra-short bunch, shorter than 1 ps, is required when generating THz light by coherent synchrotron radiation (CSR), or coherent transition radiation (CTR). 1 ps (0.3 mm) is equivalent to the wavelength of 1 THz light. When the bunch length is shorter than this, the radiation is enhanced coherently and the power would be proportional to the square of the number of electrons. That means an ultra-short bunch with high charge would be a useful tool for an intense THz light source. Such an electron bunch is available using a number of buncher systems, but in that case the whole system gets large [6]. It is the best if such an electron bunch is generated by an electron gun. Ultra-short bunch is also useful for improving temporal resolution in pulse radiolysis experiment, and for improving luminosity in laser-Compton scattering.

BUNCH COMPRESSION

In a photocathode rf gun, the initial electron transverse/longitudinal profile is controlled by the laser pulse. One might think of using a femtosecond laser to generate a femtosecond bunch. But in this way, the charge density gets very high and ends up with a bunch length more than 1 ps due to the space charge effect. For this reason, we conceived ECC rf gun, which can compress the bunch after being accelerated enough. In ECC rf gun, the ECC is attached right after the 1.6 cell. That means the beam is firstly accelerated around 4-5 MeV by 1.6 cell and then energy chirped by ECC. Energy chirp is produced by the off-crest rf phase as shown in Fig. 1.

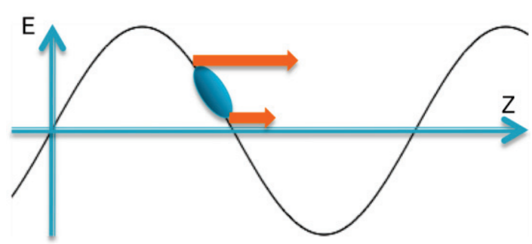

Figure 1: Off-crest rf phase acceleration in ECC.

The cavity structure, especially the length of iris between full cell and ECC (2nd iris), and the length of ECC itself is optimized so that the beam rides on the best phase to acquire energy chirp. Figure 2 describes the cavity structure of ECC rf gun.

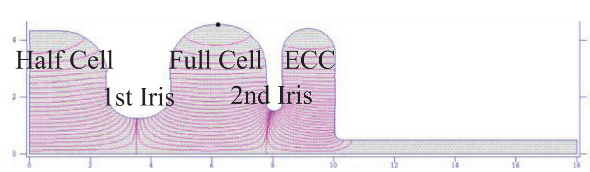

Figure 2: SUPERFISH Drawing of ECC rf gun.

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†advanced-yuya@asagi.waseda.jp

In addition to the shortened iris and cell, electric field at ECC is made to be higher than other cells. These features are needed to control the phase and chirp the energy linearly and intensely. After the energy is chirped, the bunch gets shorter and shorter as it drifts through the beam line because of the difference of velocity. This process is called the velocity bunching [7]. This could be explained by the rotation of phase space distribution. Figure 3 shows the schematic of bunch compression.

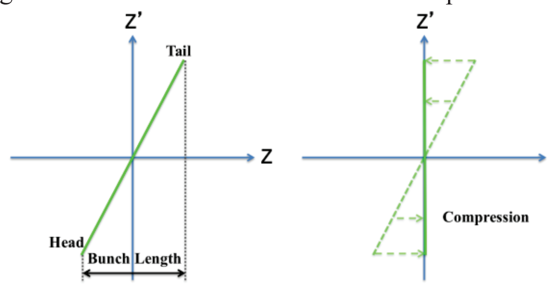

Figure 3: Bunch compression in phase space.

If the energy chirp were linear (left), the bunch would be compressed perfectly (right). Figure 4 shows the simulation result of bunch compression performed by PARMELA. As you can see, the bunch length (blue line) is compressed down to 86 fs at 2.4 m away from cathode.

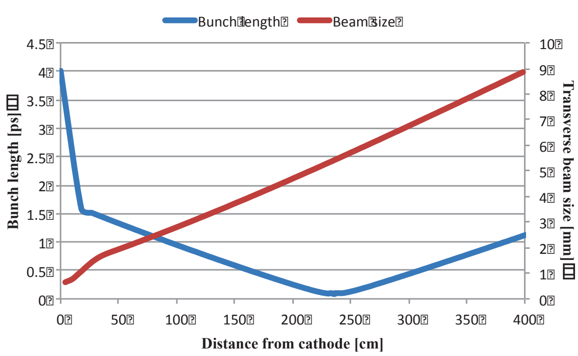

Figure 4: Bunch length and Beam size as a function of distance from cathode.

EXPERIMENTAL SETUP

ECC RF Gun

We have confirmed by simulation that ECC rf gun is worth making so we have manufactured it. The picture of ECC rf gun is shown in Fig. 5.

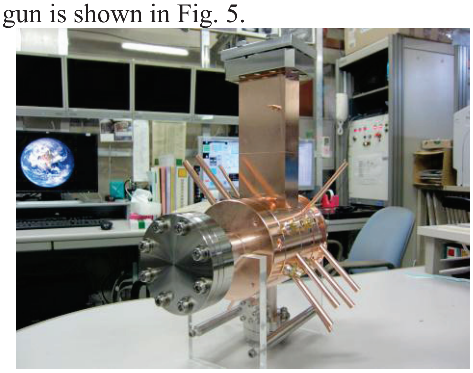

Figure 5: ECC rf gun.

The measured Q-value and shunt impedance was 10860 and 5.57 MOhm respectively. By bead pull measurement, the electric field in ECC was 1.22 times as higher as that in full cell and half cell, though the design was 1.5.

Beamline

We have installed the ECC rf gun into our compact accelerator system. The schematic of beamline is shown in Fig. 6. UV pulse laser is guided by a mirror inside the beamline.

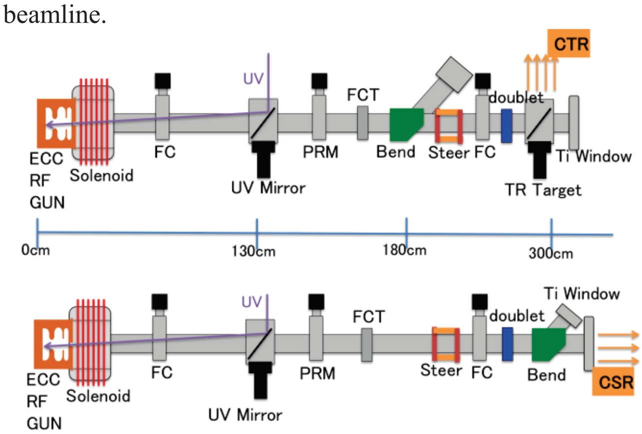

Figure 6: Beamline layouts for CTR (above) and CSR (below).

From PARMELA simulation, the most compressed point of electron bunch from the real ECC rf gun would be at the distance of 3 m from cathode. Therefore the Al target for CTR, or bending magnet for CSR was put at this point. The beam energy was also measured using the bending magnet and the result was 4.1 MeV maximum.

THz Detector

CTR and CSR were detected by Schottky barrier diodes (SBD). We used several diodes, which has sensitivity in different THz region. We used 0.05THz (millitech, 40-60 GHz), 0.1 THz (WiseWave, 75-110 GHz), 0.3 THz (WiseWave, 220-330 GHz), and 0.6 THz (Virginia Diodes, 500-750 GHz). The aperture becomes smaller as the frequency gets higher. They operate in room temperature.

RESULTS AND DISCUSSION

Transition Radiation

We have already tested CTR and CSR detection using beamline setup shown in Fig. 6. In this paper, we will mainly discuss about CSR detection. Figure 7 is the raw waveform of CTR detection by 0.1 THz SBD and electron charge by current transformer. We have successfully detected 0.1 THz CTR using a compressed electron bunch from ECC rf gun. The detail discussion is described by the CSR results in the following section.

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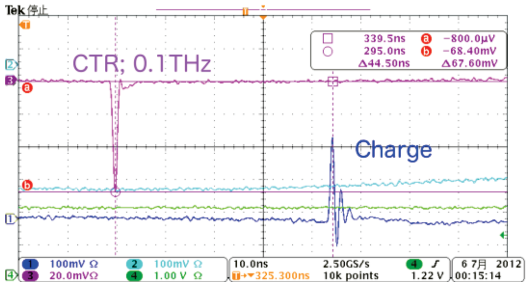

Figure 7: Raw data of 0.1 THz CTR.

Synchrotron Radiation

CSR was also detected successfully. Figure 8 shows the phase dependence of 0.05 THz CSR.

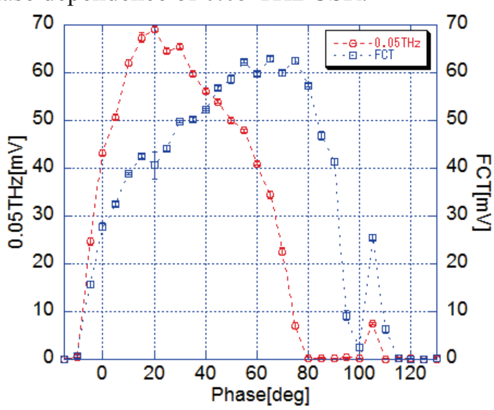

Figure 8: Phase dependence of 0.05 THz CSR.

In Fig. 9, detectors are compared. Note that the red plots represent 0.1 THz with a band-pass filter (BPF), which passes electromagnetic wave around 0.2 THz.

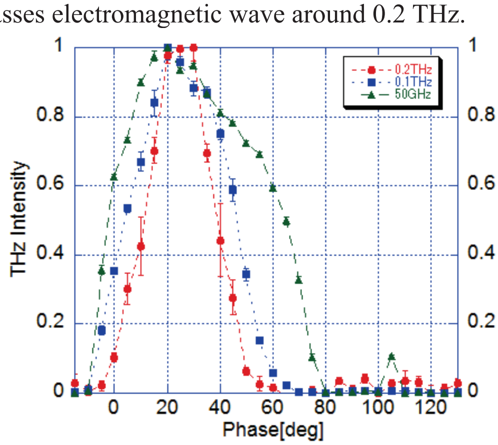

Figure 9: Phase dependence of 0.1 THz with BPF (0.2 THz) (red), 0.1 THz (blue), and 0.05 THz (green).

It is obvious that 0.1 THz with BPF (red line) i.e. 0.2 THz radiation is narrower than 0.1 THz alone (blue line). This behavior was expected by the simulation results of PARMELA and GPT. Rf accelerating phase of 20 deg was the best phase to compress the electron bunch. Due to the successful results of 0.2 THz detection, we can estimate that the bunch length is surely shorter than 1ps, and could be less than 500 fs by the calculation of the SR spectrum and coherent enhancement.

We have also confirmed that the radiated power is proportional to the square of electron bunch charge, and our synchrotron radiation is emitted coherently. It is shown in Fig 10.

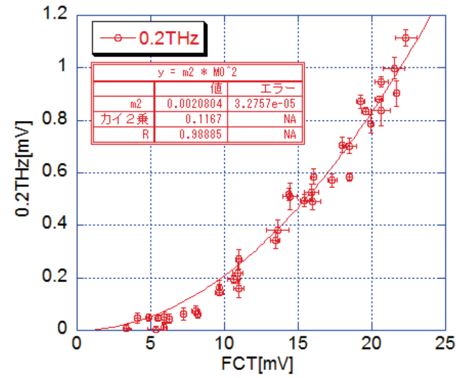

Figure 10: Coherent synchrotron radiation.

0.3 THz and 0.6 THz SBDs were also tested but could not be detected due to the small aperture. Moreover, the critical frequency in current our setup was approximately 0.3 THz. Hence we need more intense radiation and to improve our setup in order to measure 0.3 THz.

SUMMARY AND FUTURE PLANS

In this paper we described about specially designed photocathode rf gun, ECC rf gun, that can generate an ultra-short bunch. We have successfully measured the THz radiation both by CTR and CSR. From these results, we can estimate the bunch length as 500 fs. For the next step, we are going to build an interferometer and study the precise frequency of CTR. We are also planning to apply coherent THz light for imaging use.

REFERENCES

[1] K. Sakaue, et al., Proc. of IPAC'11, TUPC058, (2011)
[2] Y. Koshiba, et al., Proc. of IPAC'12, TUPPD058, (2012)
[3] Y. Hosaka, et al., Radiat. Phys. Chem. 84.10-13 (2013)
[4] Y. Yoshida, et al., Proc. of IPAC'12, THPPR049, (2012)
[5] K. Sakaue, et al., Radiat. Phys. Chem. 77.1136-1141(2008)
[6] D. Kedar and T. Sen, "Bunch Compression and CSR Study in ASTA" (2012).
[7] L. Serafini and M. Ferrario, AIP Conference Proc. 581(2001)87.