

# ULTRA-SHORT ELECTRON BUNCH GENERATION USING ENERGY-CHIRPING CELL ATTACHED RF ELECTRON GUN\*

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## Abstract

We have been developing an Energy-Chirping-Cell attached RF electron gun (ECC-rf gun) for generating ultra-short electron bunches. ECC-rf gun has extra cell at the end of gun cavity in order to chirp the bunch energy. Such a bunch can be compressed by the velocity difference though the drift space. We have already installed it to our accelerator system and successfully observed a coherent synchrotron/transition radiation at 0.3 THz. It is clear that the bunch length was short enough to generate 0.3 THz, which corresponds to less than 500 fs bunch length was achieved if we assume the gaussian shape. In this conference, the principle of ECC-rf gun, the recent results of bunch length measurement and future prospective will be presented.

## INTRODUCTION

A photocathode rf electron gun is a good alternative for a high brightness electron source due to the low emittance and short bunch, which controlled by the laser pulse irradiating to the photocathode. We have been developing a photocathode rf gun for the application researches such as a laser-Compton scattering [1] and a pulse radiolysis experiment [2]. Our rf gun cavity is originally based on an S-band BNL typeIV 1.6 cell cavity. We have been improving the rf gun cavity, Ref. [3] reported an improvement of rf tuner system and Ref. [4,5] reported an improvement of the mode frequency separation. Also, we adopted a Cs-Te photocathode for multi-bunch beam operation which caused by the high quantum efficiency of Cs-Te [6]. Based on these improvement on the rf gun, we designed a new type rf gun cavity for an ultra-short electron bunch generation [7]. The energy of electrons from rf gun is relatively low of up to 5 MeV. Moreover, the initial electron energy from the cathode is almost zero-energy. For such an electron beam, the hard space charge effect will enlarge the bunch length immediately. One solution for achieving the ultra-short bunch is to reduce the number of electrons in the bunch. Several hundred of fs bunch was achieved with several pC/bunch charge [8]. The other solution, which we employed, is to compress the bunch at certain point. This technique make it possible to produce an ultra-short (less than 500 fs) bunch with more than 100 pC/bunch charge. For re-

alizing this technique, we designed an energy-chirping-cell attached rf gun (ECC-rf gun) cavity.

The detailed design and first experimental results were described in Ref. [7]. We attached specially designed cell for the gun in order to chirp the bunch energy. The 10 ps initial bunch is accelerated up to 4-5 MeV in the conventional 1.6 cell, then the ECC chirps the energy linearly. The linearly energy chirped electrons in the bunch have a different energy, i.e. velocity, so that the latter electrons catch up the former electrons at a certain point. The parameters and results of simulation design are shown in Table 1. The design was performed by GPT (General Particle Tracer). As

Table 1: Parameters and Results of ECC-rf Gun on GPT Simulation

Quantity	Value
Charge	100 pC/bunch
Ini. bunch length	4.3 ps (rms)
E at cathode	100 MV/m
Injection phase	20 deg
Energy	4.24 MeV
Bunch length	88.4 fs (rms)
Compressed point	2.3 m

shown in Table 1, an ultra-short bunch of less than 100 fs (rms) was achieved on the optimum condition. The 4.3 ps (rms) bunch is firstly compressed by the bunching effect in the gun cavity, and gradually compressed due to the linear energy chirp down to 88.4 fs (rms).

In this paper, we describe about the bunch length measurement by coherent transition radiation (CTR). The experimental setup is described in Sec. 2; followed by the result and discussion of CTR experiments. In Sec. 4, we summarize our results.

## EXPERIMENTAL SETUP

In this section, we describe about our experimental setup. First, the accelerator system is described and followed by the THz CTR generation and detection.

### Accelerator System

The experiments were performed at Waseda university. The schematic of our accelerator system is shown in Fig.

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1. Our accelerator system is based on only the rf gun cav-

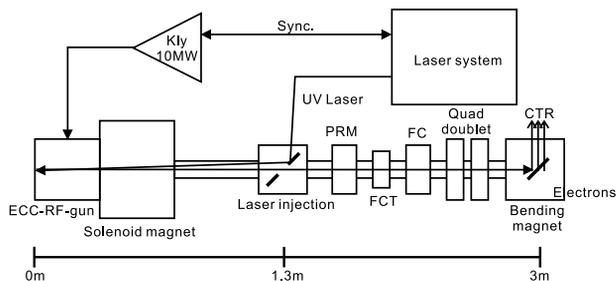


Figure 1: The schematic of the experimental setup.

ity. The electron beam energy is up to 5 MeV. A 10 MW klystron drives the rf gun cavity and produce more than 100 MV/m electric field inside the cavity. The photo electrons are produced by the 262 nm UV pulsed laser. The laser system is synchronized with rf master clock with the accuracy of about 0.3 ps. The UV laser is injected to the cathode from the center-holed aluminum mirror located in the beam line. The electrons are accelerated and energy chirped by the ECC-rf gun and pass through the solenoid magnet, fast current transformer (FCT), and the quadrupole magnets; then focused onto the aluminum target in order to produce the transition radiation. The TR, including THz frequency region, is extracted to the air through the crystal quartz window. For generating a coherent TR, not only the bunch length but also the transverse beam size is important, which is well known as a transverse form factor. Thus we installed the focusing magnets before the target. In the target chamber, both screen monitor and TR target can be inserted on the beam line. We performed CTR generation after confirming the electron beam size was surely small by the screen monitor.

### THz Detector

As a THz CTR detector, we used 5 of narrow band schottky barrier diodes (SBD). The center frequencies were 0.05 THz, 0.1 THz, 0.2 THz, 0.3 THz and 0.6 THz. These SBDs have about 10 % spectrum aperture around the center frequency described above. The CTR spectrum can be briefly measured by these SBDs because we can estimate how high frequency was observed. If we assume the Gaussian shape bunch longitudinal distribution, we can estimate the bunch length according to the form factor of the Gaussian bunch and the result above.

## RESULTS AND DISCUSSIONS

Firstly we show the simulation results of bunch length under the operating condition at Waseda university. We designed to achieve less than 100 fs bunch with 100 MV/m accelerating gradient in the gun, however, the klystron at Waseda university is not enough for the 100 MV/m electric field. The electric field was limited by 75 MV/m. Thus we

made simulation for such situation. Fig. 2 shows the simulation result of bunch length at 3 m away from the cathode as a function of rf phase. The expected bunch length was

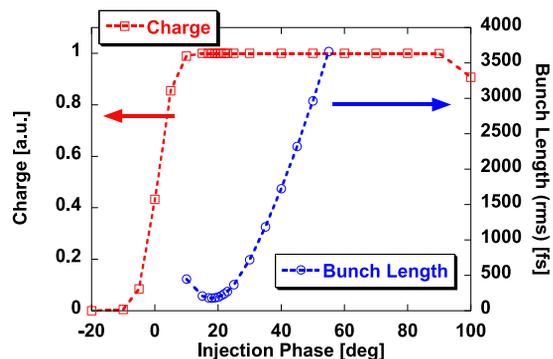


Figure 2: The result of simulation based on the operation condition at Waseda university.

180 fs (rms) with 3.7 MeV energy at the TR target position. The bunch length was minimum at 20 deg rf phase.

As an experiment, we firstly performed an energy measurement. Figure 3 shows the result of energy measure-

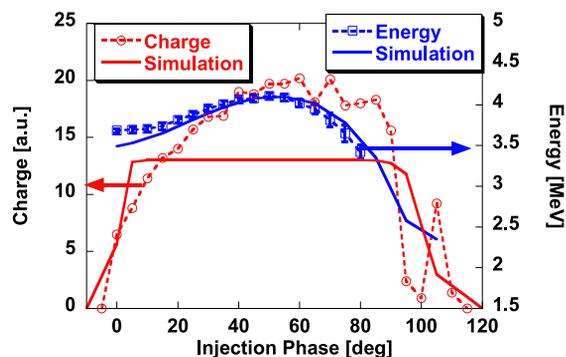


Figure 3: Measurement results of electron energy and bunch charge as a function of the rf phase.

ment compared with the simulation. The results show good agreement with the simulation. The ECC will chirp the energy, thus the agreement of electron energy with simulation indicates the ECC-rf gun would work correctly. Around the most bunch compressed phase of 20 deg, the energy was increased as the rf phase increase. This also show the phenomenon that the phase in ECC was off-crest and correctly energy chirped.

After the confirmation of beam energy, we performed a CTR measurement. The electron beam size on the target was 0.6 mm, which is enough for generating 0.3 THz but not for 0.6 THz. We switched 5 of SBDs and measure the THz intensity as a function of the rf phase. Figure 4 shows the result. The 0.6 THz center freq. SBD could not detect the CTR. It would be caused by the transverse

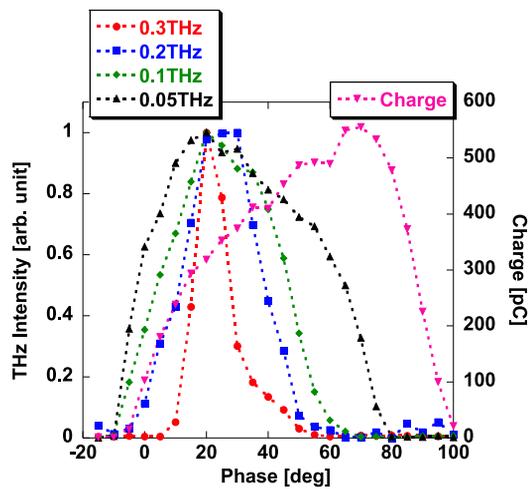


Figure 4: The narrow band SBD signals as a function of the rf phase.

form factor of beam size 0.6 mm. Other SBDs could measure the CTR from the Al target. As shown in Fig. 4, the CTR intensity had maximum around 20 deg of phase for all SBDs. Also, the lower frequency CTR was detected along the larger phase region. It is indicated that the minimum bunch length was achieved around 20 deg and was gradually lengthened as the phase apart from 20 deg as expected by simulation shown in Fig. 2.

Then, let us estimate the bunch length from the result of Fig. 4. The 0.3 THz CTR was successfully observed by the bunch from ECC rf gun. According to the sensitivity of SBD, the THz radiation cannot detect unless the radiation was coherently enhanced. Therefore it is clear that the 0.3 THz frequency was coherently enhanced. Considering the form factor of Gaussian distribution, it can be estimated that the bunch was compressed less than 500 fs (rms). Hopefully, the reason why the 0.6 THz SBD could not detect the signal was caused by the transverse form factor, we believe that the bunch was correctly compressed down to about 200 fs as expected in Fig. 2. It should be noted that the discussion above was assuming Gaussian distribution.

## SUMMARY

We have developed a new type rf electron gun for ultra-short bunch generation, named Energy-Chirping-Cell attached rf gun (ECC-rf gun). This unique gun has a possibility to produce an ultra-short bunch with less than 100 fs (rms) by velocity bunching. We manufactured an ECC-rf gun and tested at Waseda University accelerator system. The bunch length was measured by the coherent radiation. The narrow band schottky barrier diodes were used for observing coherent synchrotron radiation and successfully observe 0.3 THz radiation. It was indicated that the bunch would be less than 500 fs (rms) due to the 0.3 THz

coherent radiation. It should be noted that the result assumed Gaussian bunch distribution. In near future we will perform a direct bunch length measurement by rf deflecting cavity [9,10]. Also we plan to apply this unique cavity for THz radiation sources and/or dynamic Electron diffraction microscopes.

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