ULTRA-SHORT ELECTRON BUNCH GENERATION BY A PHOTOCATHODE RF GUN*

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Abstract

We have been studying on the accelerator physics at Waseda University with BNL type 1.6cell RF gun. Such photocathode RF gun can generate low emittance and short bunch electron beam. Generating ultra-short electron bunch (shorter than 1ps) in a compact accelerator system would be meaningful because some applications need to be miniaturized, THz imaging, for example. However short the laser pulse is, the bunch length would be longer than 1ps due to the severe space charge effects. For the purpose of generating ultra-short electron bunch in compact system, we have newly designed Energy Chirping Cell attached RF gun (ECC RF gun). ECC is attached subsequently to the 1.6 cell. The role of ECC is to chirp the electron energy so that the electron bunch is compressed by velocity difference as it drifts. Simulation results show ECC RF gun can compress the electron bunch down to 200fs (rms) with 100pC electron charge. We have successfully measured the coherent THz light by synchrotron radiation and transition radiation. From these consequences, we infer that the bunch would be compressed into shorter than 500fs. In this paper, we report the results of the bunch length measuring experiments and future plans.

INTRODUCTION

At Waseda University, we have built a compact accelerator system (2m×3m), which consists of picosecond UV pulse laser and S-band Cs-Te photocathode RF electron gun . This RF gun is based on BNL type IV 1.6 cell cavity and capable accelerating high quality electron bunches up to the energy of 5MeV. In our system, the RF frequency is 2856MHz and Cs-Te is used for the cathode. Such photocathode RF guns can generate high-quality electron beam, that is to say low emittance, high brightness, and short pulse. At Waseda University, the beam has been used for applications such as pulse radiolysis experiment for radiation chemical reactions [1], soft X-ray generation via laser-Compton scattering [2] and a laser profiler [3]. Besides such beam applications, we have been developed an RF gun itself in cooperation with High Energy Accelerator Research Organization (KEK).

Ultra-short Electron Bunch

If ultra-short electron bunch (<1ps) is available from the RF gun, it leads some beam applications to be improved. At the least at Waseda, temporal resolution in pulse radiolysis system and luminosity in laser-Compton scattering will be improved. And in addition, ultra-short electron bunch is able to produce coherently enhanced THz radiation. At this time the intensity of THz radiation increases with the square of the bunch electron charge. Therefore in order to achieve high power THz radiation, it is necessary to keep a certain amount of the bunch charges besides bunch compression. The magnetic compression is widely used to compress energy chirped electron bunch. This method has made successful achievements [4], but leads the system to increase in size. The aim of our study is to generate ultra-short electron bunch by use of an RF gun alone.

BUNCH COMPRESSION

Generally in photocathode RF gun, the initial beam transverse/longitudinal profile can be controlled by the laser pulse. It seems that femtosecond laser would generate ultra-short bunch, but in simulation, we have confirmed that the bunch length gets longer than 1ps due to space charge effects. Therefore we have considered improving RF gun.

Energy Chirping Cell Attached RF Gun

Now we have newly designed an RF gun named Energy Chirping Cell attached RF gun (ECC RF gun) in order to achieve ultra-short bunch just with an RF gun itself [5][6].

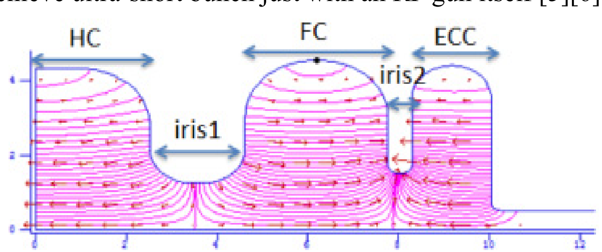

Figure 1: The cavity structure of the ECC RF gun.

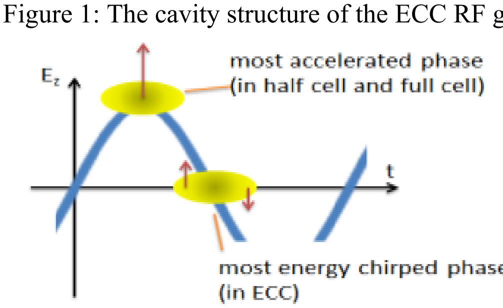

Figure 2: Off-crest acceleration in ECC.

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As shown in Figure 1, the Energy Chirping Cell (ECC) is attached subsequently to the 1.6 cell: half cell and full cell. The ECC RF gun is designed to be operated in π mode, similar to the conventional RF gun. Figure 2 shows energy chirping is preceded at off-crest RF phase. In half cell and full cell, the bunch is accelerated around the crest, on the other hand the bunch energy is linearly modulated around zero-crossing phase in ECC.

Therefore in the ECC RF gun, the bunch is firstly accelerated up to around 4MeV in 1.6cell, after that the bunch energy is chirped linearly. The energy chirped bunch gets gradually compressed as it drifts. We have confirmed such velocity bunching by PARMELA and GPT, a beam tracking code. Shown in Figure 3, the bunch length in the longitudinal phase space gets most compressed down to around 200fs (rms) at the 3m from the cathode. At this time initial pulse width is 4.3ps (rms) and the bunch has enough charge (100pC). Moreover, initial RF phase significantly affects the ultra-short bunch generation. As shown in Figure 4, the bunch gets compressed only around 30 degree. And we show the simulation results in Table 5.

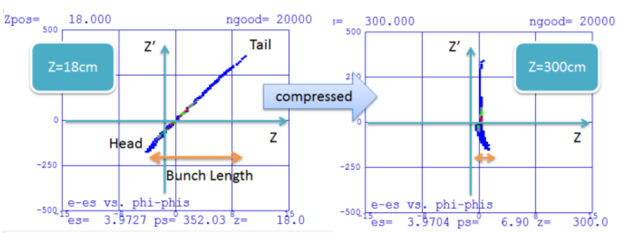

Figure 3:The longitudinal phase space distribution right after ECC (left), distance of 3m from cathode (right).

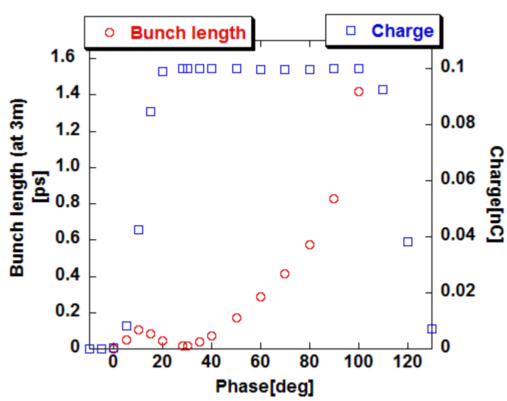

Figure 4: RF phase dependence of the bunch length.

Table 5: The Results of ECC RF Gun Simulation

Energy	3.98MeV
Charge	0.1nC
Minimum bunch length	158fs (rms)
The most compressed distance	3.07m
Normalized emittance	4.18πmm-mrad

By means of simulation, we have confirmed that the ECC RF gun generates ultra-short electron bunch, therefore we have started to manufacture the ECC RF gun. Figure 6 shows appearance of manufactured ECC RF gun.

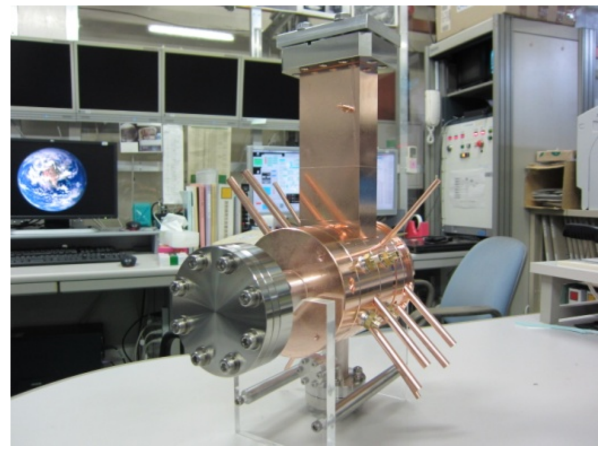

Figure 6: Manufactured ECC RF gun.

EXPERIMENTAL SETUP

We installed the ECC RF gun in our accelerator system. In order to measure a synchrotron radiation (SR), we built a beam line as illustrated in Figure 7. We put the bending magnet at the point of 3m from cathode, where the bunch got most compressed. And then SR passed through the z-cut quartz window, was measured by use of narrow band schottky barrier diodes (SBDs).

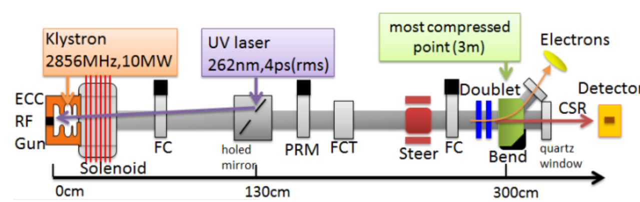

Figure 7: Experimental setup

Schottky Barrier Diode

In this spectroscopy experiment, we used several Schottky Barrier Diodes (SBDs), which have various narrow sensitive frequency ranges in THz region. The Table 8 shows the specs of these apparatuses.

Table 8: The Specifications of SBDs and BPF

Model	DXP-19	FAS-10SF-01	BPF
Manufacturer	Millitech	Wisewave	TYDEX
Sensitive range [THz]	0.04-0.06	0.075-0.11	0.18-0.22
Sensitivity [mV/mW]	1000	500	-
Name	0.05THz	0.1THz	0.2THz

Note that 0.2THz detector consists of 0.1THz SBD and 0.2THz BPF. 0.1THz SBD seems to have small sensitivity at 0.2THz.

EXPERIMENTAL RESULTS AND DISCUSSION

Coherent Synchrotron Radiation Measurement

When the bunch length σ_z is regarded as short enough as the wave length of the radiation, the radiation gets enhanced coherently with square of bunch charge. Assuming the bunch form as Gaussian, the power of the synchrotron radiation is expressed as;

$$P_{\rm all}(\omega) = N(1+(N-1)e^{-(\omega\sigma_z)^2})P_0(\omega) \qquad (1)$$

where N is the number of electrons and therefore when bunch charge is 100pC, N is 6×10^8. $P_0(\omega)$ is power of the radiation from one electron and $P_{all}(\omega)$ is power from the bunch. The spectrum of the SR and CSR is calculated by SPECTRA as shown in Figure 9. 3.7MeV electron bunch can generate THz radiation in our beam line. In our setup, the cut-off frequency is 0.6 THz. But considering the bunch is kicked by a fridge weak magnetic field the cut-off frequency becomes as lower as 0.3 THz. It is also obvious from Figure 9 and Equation (1) that shorter bunch can generate CSR at higher frequency. Therefore we can estimate the bunch length by measuring CSR frequency.

We have confirmed Coherent Synchrotron Radiation (CSR) by plotting THz intensity as a function of the bunch charge in Figure 10. It is evident from the plots that

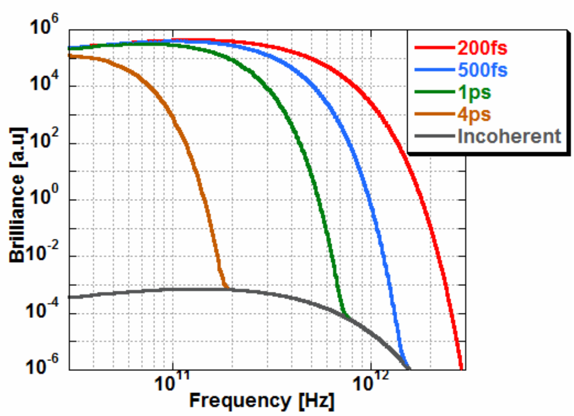

Figure 9: CSR spectrum calculated by SPECTRA (3.7MeV, 100pC).

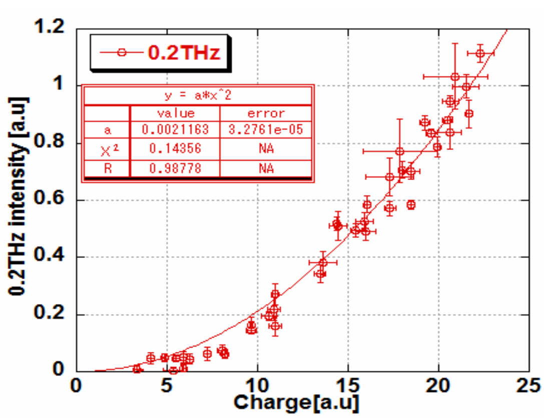

Figure 10: 0.2 THz coherent synchrotron radiation.

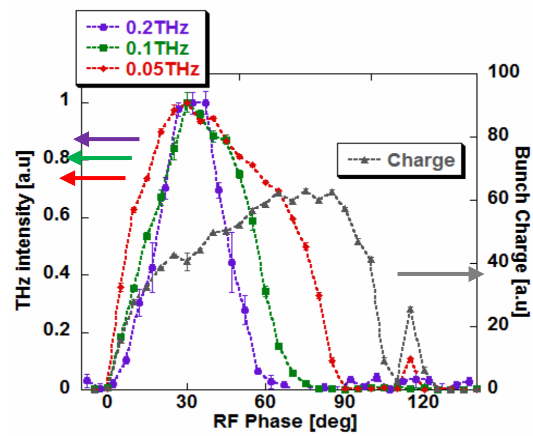

Figure 11: Phase dependence of several detectors.

we have obtained at least up to 0.2THz CSR.

We have successfully measured 3 various narrow THz regions, around 0.05THz, 0.1THz and 0.2THz. As shown in Figure 11, we compared the detectors. Each CSR has a peak at the 30 degree. Moreover, intensity plots become narrow as the frequency of the CSR becomes higher one. These are surely expected by the Figure 4.

From the CSR spectrum (Figure 9) and the successful results of 0.2 THz CSR detection (Figure 10), we can estimate the bunch length is shorter than 500fs. Moreover, having even 0.2 THz CSR the spread width intensity profile (Figure 11), this implies that the higher frequency CSR is produced at the optimum RF phase of 30 degree. We believe the bunch is exactly compressed down to the 200fs at the optimum phase.

SUMMARY AND FUTURE PLANS

In this paper, we described the ECC RF gun newly designed to generate ultra-short electron bunch. We have successfully measured the CSR, thus we estimated the bunch length was compressed down to 500fs (rms). As further bunch length measurement, we consider spectroscopy by use of an interferometer. In the near future, we intend to directly measure the bunch length by use of an RF deflector [7].

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