Ultra-Short Electron Bunch Generation by a Photocathode RF Gun

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Outline

1. Introduction
   • Ultra-Short Electron Bunch
   • What’s THz wave?
   • Motivation of our Work

2. Bunch Compression
   • What’s ECC RF Gun?
   • How does the Bunch get Compressed?

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   • Accelerator System at Waseda
   • Generation of Coherent Radiation

4. Summary
Introduction

In Waseda University, We’re studying **accelerator physics**.

Some Applications

• Pulse Radiolysis

• Laser-Compton Scattering

Furthermore,

**RF gun development**

We aimed to make a new RF gun which generates **ultra-short** electron bunch.

**For What?**
Ultra-Short electron bunch leads to...

- the temporal resolution of Pulse radiolysis
- the luminosity of Laser-Compton Scattering

(At least in our Lab.)

And...

generate High Power Coherent THz waves!
Coherent THz Radiation

**Short** Electron bunch

Coherent Radiation

\[ \sigma < \lambda \rightarrow I_{coh} \propto N^2 \]

\[ \times N \] N: number of electrons

(100pC \(\rightarrow\) N=6 \(\times\) 10^8)

Incoherent Radiation

\[ \sigma > \lambda \rightarrow I_{inc} \propto N \]

Spectrum of Coherent Synchrotron Radiation

(3.7MeV, 100pC bunch, calculated by SPECTRA)

when Gaussian

\[ f(\omega) = e^{-\left(\frac{\omega \sigma_z}{\omega \sigma_z}\right)^2} \]

N: number of electrons

Shorter bunch brings coherent radiation at higher frequency

bunch length estimation
What’s Terahertz wave?

Terahertz wave (THz wave) is electromagnetic wave located between radio frequency and infrared light.

![Terahertz wave diagram](diagram.png)

**Terahertz Imaging**

MDMA (Narcotic)  aspirin (Medicine)  methamphetamine (Stimulant)

**THz Applications**

**THz Imaging**

- MDMA (Narcotic)
- aspirin (Medicine)
- methamphetamine (Stimulant)


Distinguishable!
Motivation

For THz applications, Compact and High Power THz light Source is required.

New RF Gun which generates Ultra-Short Bunch just by itself (keeping a certain amount of charge), (without Magnetic Compressors or Acceleration tubes...) compact

measurement by measuring THz radiation, confirm new RF gun generates ultra-short bunch
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Bunch compression

In conventional photocathode 1.6cell RF gun, bunch length could be controlled by the laser pulse width.

However, the bunch length ends up to be more than 1ps due to space charge effects.
A new RF Gun = **ECC RF Gun**

We’ve newly designed an RF Gun.

Compress the bunch down to several 100 fs keeping some quantity of bunch charge.

**Energy Chirping Cell attached RF Gun (ECC RF Gun)**

- In ECC, the bunch energy gets chirped linearly.

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**Cavity structure of the ECC RF Gun**

**Off-crest RF phase acceleration in ECC**
ECC RF Gun Simulation

The Bunch gets compressed by velocity bunching.

- Gamma: The bunch gets compressed around certain RF Phase simulated by PARMELA and GPT.
- Drift space: The most compressed is at 3m from the cathode.
- Conventional gun vs ECC RF Gun: Compared to a conventional gun, the ECC RF Gun shows a shorter bunch length.
- Simulation: The simulation shows the bunch length gets compressed to 200fs (rms) with 100pC bunch!!
ECC RF Gun manufacturing

Confirming bunch compression via simulation, we started manufacturing the ECC RF Gun.

cavity parameters (simulation) | beam parameters (simulation)
--- | ---
| ECC RF Gun | ECC RF Gun |
Q-value | 13932 | Charge | 100pC |
Frequency ($\pi$ mode) | 2856.066 MHz | Energy | 3.7MeV |
Frequency ($\pi/2$ mode) | 2852.964 MHz | most compressed point | 3.02m |
Field balance ($E_H: E_F: E_{ECC}$) | 1 : 1 : 1.22 | bunch length | 180fs (rms) |

 Installed ECC RF Gun
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Accelerator System at Waseda

Klystron 2856MHz, 10MW
UV laser 262nm, 4ps (rms)

most compressed point (3m)

Electrons (4MeV)
Detector

Solenoid magnet
holed mirror

degree of vacuum: \(\sim10^{-7}\) Pa

Cs-Te photocathode

Beam Line (downstream)

Bending magnet at 3m

Synchrotron Radiation

Bending magnet at 3m

UV injection

FC : Faraday Cup
FCT : Fast Current Transformer
PRM : Profile Monitor screen

Schottky Barrier Diode (SBD)
Detecting Coherent Synchrotron Radiation (CSR)

Each detector has different narrow band sensitivity in the THz region.

We can estimate the bunch length by measuring the frequency of CSR.

Specifications of detectors:

<table>
<thead>
<tr>
<th>Name</th>
<th>0.05THz</th>
<th>0.1THz</th>
<th>0.2THz</th>
<th>0.6THz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>DXP-19</td>
<td>FAS-10SF-01</td>
<td>BPF</td>
<td>WR1.5ZBD</td>
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<tr>
<td>Manufacturer</td>
<td>Millitech</td>
<td>Wisewave</td>
<td>TYDEX</td>
<td>VDI</td>
</tr>
<tr>
<td>Sensitive range [THz]</td>
<td>0.04-0.06</td>
<td>0.075-0.11</td>
<td>0.18-0.22</td>
<td>0.5-0.75</td>
</tr>
<tr>
<td>Sensitivity [mV/mW]</td>
<td>1000</td>
<td>500</td>
<td>-</td>
<td>750</td>
</tr>
</tbody>
</table>
We can see 0.05THz, 0.1THz and 0.2THz radiation signal. confirming **Coherent** Synchrotron Radiation

$bunch$ length gets compressed down to 500fs!
Experimental Results 2

also confirming **bunch compression** (depends on RF Phase)

comparison of different detectors **(results)**

peak at **30deg**

( most compressed at **30deg** )

the intensity profile gets **narrower** as the frequency becomes **higher**
Summary

- We have newly designed and manufactured the **ECC RF Gun** in order to achieve **Ultra-Short** electron bunch in a compact system.
- The bunch gets compressed down to **500fs** (rms) because we have successfully measured the **Coherent THz Radiation at 0.2THz**.
Future Plans

• In the next step, we’re going to make an **interferometer** and obtain **frequency spectrum** of Coherent Transition Radiation.

  **Measure the bunch length more precisely!**

• Now an **RF deflector** is being tested in our University.

  **Directly measuring**
  
  the bunch length!
Thank you for your attention