DESIGN OF A 0.6-CELL PHOTOCATHODE RF GUN FOR FED

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Abstract

Final goal of this study is the development of single cell radio-frequency (RF) electron gun which is optimized for the femotosecond electron diffraction (FED) experiment. This study will open a technology basis to fabricate the RF gun easily for the laboratory research in the femto-second (fs) chemistry at the university. The RF gun with single cell is studied to reduce the cost and effort in the preparation of the experiment setup for the FED. We conducted a preliminary simulation study to find an optimized operation condition of the RF gun to provide the best electron beam to the femtosecond electron diffraction experimentalist. In this presentation, the preliminary simulation results with PARMELA code will be presented to find the optimal operation condition of the single cell RF gun for FED.

INTRODUCTION

Femtosecond electron diffraction (FED) using an RF gun is important experimental technique to observe the femtosecond dynamics in gas phase molecule or thin film [1, 2, 3]. To achieve high charge (>1 pC) and short pulse (<100 fs) electron beam with low emittance, the RF gun with 1.6 cell which is developed for the X-ray free electron laser (XFEL) is used [4, 5, 6, 7, 8, 9].

However, the RF gun is not optimized to provide an electron beam for FED. To accelerate the electron beam up to 5 MeV for XFEL injector operation, 1.6 cell RF gun is designed. For the FED, an electron beam with the beam energy 2 MeV is enough to obtain the diffraction pattern from the specimens. To generation 2 MeV electron beam with the 1.6 cell RF gun, the electric field strength at cathode is decreased down 70 MV/m. This kind of strategy is not good choice to generate good quality (low emittance) electron beam. To prevent the space charge effect on the electron beam quality, we should keep the electric field strength as high as possible, such as 110 MV/m. Thus, we need to design the RF gun with single cell.

A single cell RF gun was studied by the Japanese group [10]. The field gradient on the cathode was reached up to 175 MV/m. However, they observed large dark current 0.15 nC/bunch with this high gradient accelerating field. The electron beam energy is 4.1 MeV. Because the purpose of this development is the application of this gun to the FEL, they tried such an extreme condition for the beam acceleration. For the FED, we need to design to accelerate the electron beam only up to only 2 MeV with very low level dark current.

* This work was supported by National Research Foundation of Korea (No. R0A-2008-000-20013-0).
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In this study, the preliminary study of the single cell RF gun and the simulation result with the gun is presented. The detail design of the single RF gun and the specifications are presented in Section 2. The simulation results with the 3D field map obtained with the single cell RF gun are shown in Section 3. The summary is provided in Section 4.

ELECTRON DIFFRACTION

The schematic experimental setup of the femtosecond electron diffraction with the single cell experiment is shown in Fig. 1.

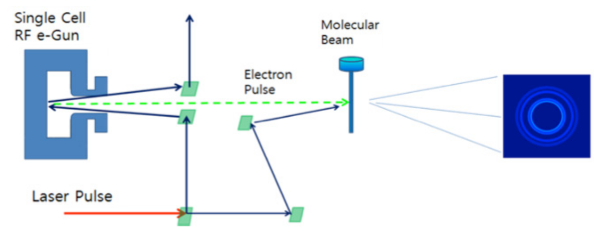


Figure 1: Schematic setup of the FED experiment with single cell RF gun.

The laser will be sent to the cathode with normal injection angle because there is no laser injection port at the RF gun. The solenoid will focus the electron beam to the specimens.

DESIGN OF SINGLE CELL RF GUN

In this section, the detail specifications of the single cell RF gun are presented. The 3D view of the single cell RF gun is shown in Fig. 2.

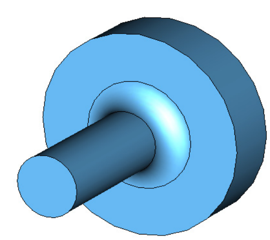


Figure 2: Schematic 3D view of single cell RF gun for FED.

Specifications of the RF Gun

The long rod shown in Fig. 2 is the vacuum pipe which is the beam propagation direction. The specifications of the single cell RF gun are given in Table 1. The resonance frequency of the single cell is 2856 MHz. The electric field strength at the cathode is 110 MV/m. The beam charge will be from 0.1 pC to 1 pC. The beam energy is 2 MeV. The quality factor of the gun is 11853.

Table 1: Specifications of the Single Cell RF Gun

Parameters	Value	Unit
Resonance frequency	2856	MHz
Cathode E field	110	MV/m
Beam charge	0.1~1	pC
Beam energy	2	MeV
Quality factor	11853	

Field Profiles in the RF Gun

The 3D electro-magnetic field profiles in the RF gun are shown in the Fig. 3. In Fig. 3(a), the side view of the RF gun is shown with the electric field profile. The lengths of arrows indicate the relative field strengths at the arrow position. In Fig. 3(b), the magnetic field profile is shown with the same arrows used in Fig. 3(a). The direction of the magnetic field is counter clockwise.

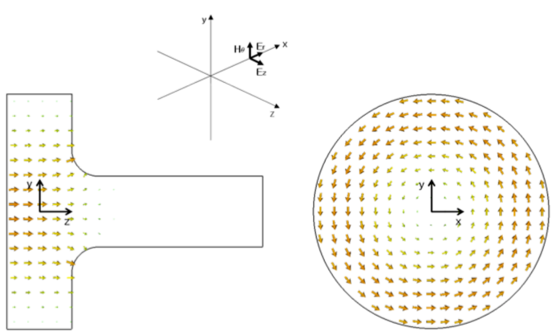
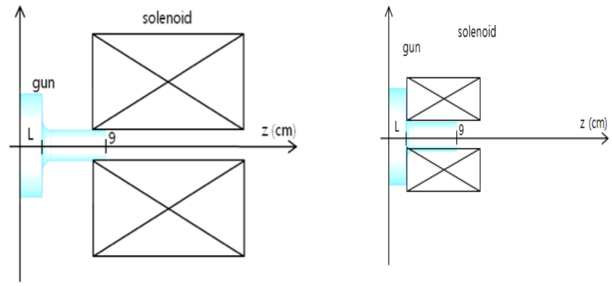


Figure 3. (a) Size view of single cell RF gun with electric field distribution. The direction of arrows is the direction of electric field in the gun. The length of arrows is the amplitude of the E-field. (b) The front view of the rf gun with magnetic field in the gun.

SIMULATION RESULTS

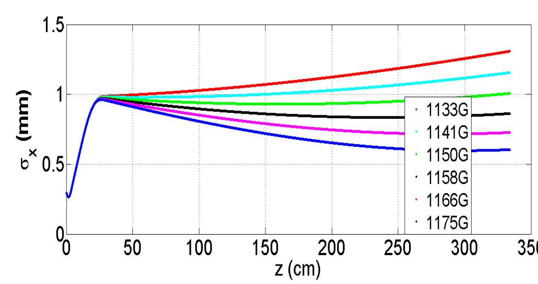
The schematic configuration for the beam dynamics simulation with the single cell RF gun is shown in Fig. 4 (a). In this preliminary study, the solenoid size and position are the same with those used in the injector simulation for XFEL. This solenoid will be redesign in next study to optimize the operation of the single cell RF gun as shown in Fig. 4(b).



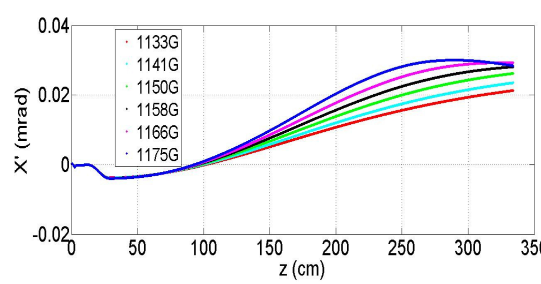
(a) (b)

Figure 4: (a) Schematic view of simulation configuration used in this study (b) Future plan of the solenoid design

A simulation results are shown in Fig. 5. The initial bunch length is 100 fs and the beam charge is 0.5 pC. In Fig. 5(a), the rms beam size is plotted with respect to the beam propagation coordinate *z*. The electron beam were focused by the solenoid field and diverged again after some drift from the gun. The focusing behaviour is different along the solenoid field strength and the charge density.



(a)



(b)

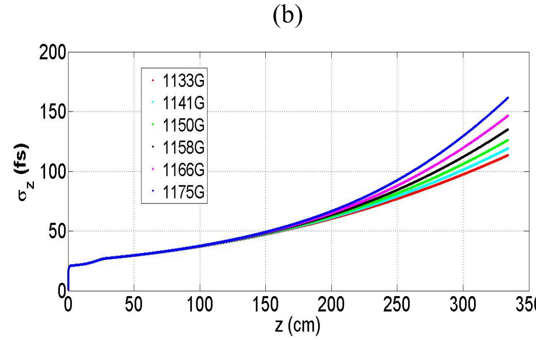


Figure 5: Simulation result with the single cell RF gun. (a) Xrms vs z (b) Divergence vs z (c) Bunch length vs z

The simulation results are summarized in Table 2. When the beam charge is less than 1 pC, we can get almost zero level divergence at the 2 m position from the cathode.

Table 2: Simulation Result (2m position)

Beam conditions (length, radius, charge)	**Divergence**	**Bunch length**
100 fs, 0.8 mm, 1 pC	-0.0036 mrad	81 fs
100 fs, 0.7 mm, 0.5 pC	0.012 mrad	62 fs
100 fs, 0.4 mm, 0.1 pC	0.00014 mrad	40 fs
50 fs, 0.8 mm, 1 pC	0.012 mrad	64 fs
50 fs, 0.6 mm, 0.5 pC	0.052 mrad	47 fs
50 fs, 0.4 mm, 0.1 pC	0.0072 mrad	27 fs

SUMMARY

We designed the single cell RF gun for the FED experiment. The beam energy 2 MeV is easily achieved with the single cell RF gun. Due to the high accelerating field at the cathode, such as 110 MV/m, the space charge effect on the emittance degradation makes no problem to make low divergence electron beam. In this simulation study, we observed that the electron beam divergence is less than 0.012 mrad at the 2 m position from the cathode when the initial bunch length at cathode is 100 fs and beam charge is less than 1 pC.

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