DEVELOPMENT OF A CS-TE CATHODE RF GUN AT WASEDA UNIVERSITY

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Abstract

A photo-cathode RF-Gun is one of the good alternatives for the electron source, because of its high gradient on the electron emitter causing small beam emittance, and tenability of initial beam profile especially for electron bunch length. Therefore, we are operating as a high brigh-tness short pulse electron source.

In last year, we have been developing a high quality electron source based on photo-cathode RF-gun which is newly designed RF cavity and has a Cs-Te cathode with high quantum efficiency [1] [2]. Improved RF-Gun cavity has four compact tuners on each half cell and full cell, which can be tuned the resonance frequency to deform the cavity wall. Also removing the Helicoflex seal and tuning holes, reduction of the dark current is expected.

According to these improvements, the Q value and shunt impedance of the new RF-Gun cavity increased 20% compared with the previous RF cavity. In addition, the dark current of cavity was reduced and the good electron beam parameters could be achieved compared with pre-vious RF-Gun with a Cu cathode.

INTRODUCTION

At Waseda University, we have been developing a high quality electron source based on photo-cathode RF-gun and performing the application experiment using high quality electron beam. Until now, we have succeeded the soft X-ray generation via inverse-Compton scattering and pulse radiolysis system for studying the early processes of radiation chemistry using electron beams generated by copper cathode RF-gun as an electron beam application.

Cs-Te RF-gun is expected to generate higher charge electron bunches with a low emittance than a copper cathode because of its high quantum efficiency. Furthermore, its high quantum efficiency enables us to generate a multi-bunch electron beam and to extend the tenability of electron beam parameters for our application experiments [3]. However, a Cs-Te cathode has a relatively short life compared with a copper, so that it has to be exchanged occasionally, thus we have developed a new RF-gun cavity which can be attached the compact cathode load-lock system. Moreover, we improved the design of an existing RF-gun cavity for the reduction of the dark current and the higher electric field.

Figure 1 shows the picture of improved photo-cathode RF-Gun system at Waseda University.

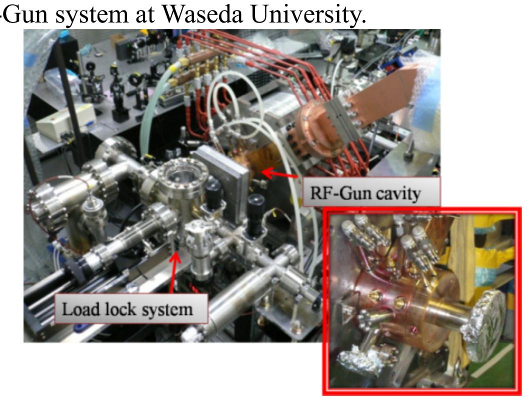

Figure 1: Improved photo-cathode RF-Gun system.

In this conference, the performance of the improved cavity, the results of electron beam generation experiments and the calculated results of beam loading effect of the multi-bunch electron beam generation will be reported.

IMPROVED DESIGN OF PHOTO-CATHODE RF-GUN CAVITY

The design of a new RF-Gun cavity was based on the conventional type operated at Waseda University and KEK-ATF. Figure 2 (a) shows the previously RF-Gun cavity. It consists of the three components such as a half cell, a full cell, and end plate. The wall of end plate was polished as a Cu cathode and attached to the half cell through a SUS plate and a Helicoflex seal, which can be tuned the resonance frequency of the half cell by changing a torque provided to a Helicoflex seal. Concerning the full cell frequency tuning, each cells are brazed so that resonance frequency of the full cell is tuned by conventional tuner with a tuning hole.

However these tuning methods are considered to be the major cause of electrical discharge and dark current source and Q-value decrease. Therefore, as the improvement of RF-Gun cavity end plate is brazed to the half cell for removing the complicated structure around the

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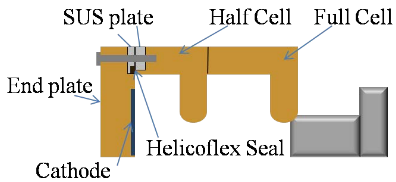
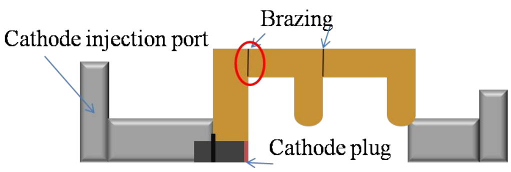
Helicoflex seal and to simply the fabrication procedure. Figure 2 (b) shows improved RF-Gun cavity design.



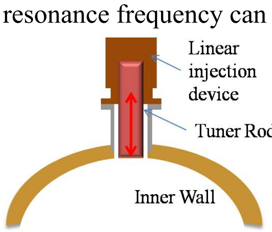
(a) Previously RF-Gun cavity design



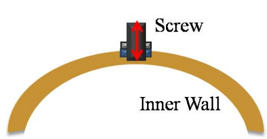
(b) Improved RF-Gun cavity design

Figure 2: Structure of the RF-Gun cavity.

In case of previously RF-Gun, the frequency tuning for the full cell is used by a tuning rod into the hole shown in Figure 3 (a). A new tuning method is also required for the half cell to tune the resonance frequency instead of Helicoflex based tuning method. Therefore, we have developed a new compact tuner using the mechanical deformation of the cavity wall. The new tuner shows Figure 3 (b). By pushing or pulling the cavity wall directly from outside, the inner wall is deformed, so resonance frequency can be tuned.



(a) Previously tuner diagram



(b) New tuner diagram

Figure 3: Schematic drawings of frequency tuner.

PARAMETERS OF THE NEW RF-GUN CAVITY

We performed a cavity parameter measurement such as Q-value, coupling constant β and shunt impedance R. Q value and coupling constant β were measured by Network analyzer and shunt impedance R was measured by bead perturbation method. The measured parameter of new RF cavity is shown in Table 1. With the bead perturbation method, R/Q is calculated by eq.1.

$$\frac{R}{Q} = \frac{\left|\int |\Delta f|\, dz\right|^2}{\pi f_0^2 \varepsilon \Delta V} \qquad (1)$$

where, Δf is frequency change due to the perturbation, ΔV is volume of the bead, ε is permittivity and f_0 is resonance frequency of π mode.

As a result, effective shunt impedance and Q-value increased 20% compared with the previous RF cavity.

Table 1: RF-Gun Cavity Parameters (previous and new)

Resonance frequency	2854.9[MHz]
Q value	12000 7900(previous)
Coupling factor β	1 0.6(previous)
R/Q	356[Ω] 240[Ω] (previous)
Shunt impedance [MΩ]	4.4[MΩ] 1.87[MΩ] (previous)

EXPERIMENTS

Dark Current Measurement

Dark current generated by the new cavity was measured by using Faraday cup. Figure 4 shows the comparison of dark current from each the previous RF cavity and the new RF cavity when 10MW power and 2.0μsec pulse was applied.(Typical operation parameters at Waseda University). It is much lower than that of the previous RF cavity with a Cu cathode at the same RF accelerating field. According to this result, we have successfully per-formed reduction of dark current at same RF power in the cavity. It is found that this effect make accelerating fields much higher.

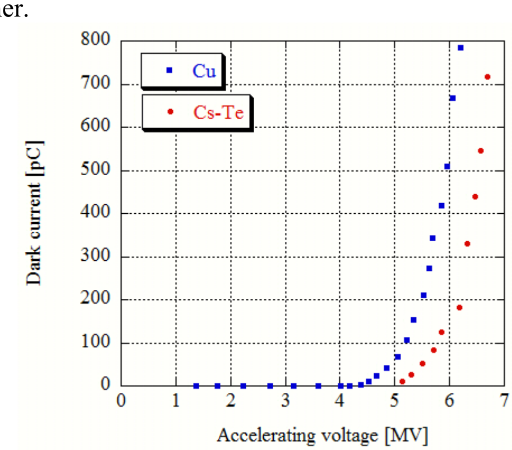


Figure 4: Result of dark current measurement.

Electron Beam Charge & Energy Measurement

Figure 5 shows one of the results of electron beam charge and energy measurements. We were able to achieve the higher charge and energy than previous RF-Gun. Table 2 shows beam parameters with new RF-Gun with a Cs-Te cathode that is obtained significantly higher than that of previous RF-Gun with a Cu cathode. At Table 2, "*" means that will be measured in near future.

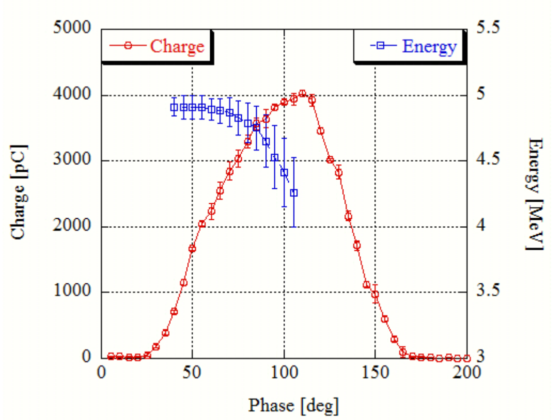


Figure 5: Charge and Energy Measurement as a function of laser injection RF phase.

Table 2: Electron Beam Parameters (previous and new)

	Previous RF-Gun (Cu cathode)	New RF-Gun (Cs-Te cathode)
Charge	~1[nC/bunch]	4[nC/bunch]
Energy	~4.6[MeV]	5[MeV]
Energy spread	1~[%]	0.6[%]
Emittance	3~[πmm mrad]	*[πmm mrad]

MULTI-BUNCH BEAM LOADING CALCULATION

In accelerating a multi-bunch electron beam, an electrical field which causing by the former electron bunches, decrease the accelerating field of latter electron bunches. So in accelerating multi-bunch beam at linac, energy difference should be caused between former bunch and latter bunch.

The beam loading effect which affects the Nth electron bunch is calculated as

$$V_{b,N} = \frac{\omega_0 Rsq}{2Q_0}\left(\frac{1-e^{-(N-2)\tau}}{1-e^{-\tau}} - \frac{1}{2}\right) \tag{2}$$

where ω_0, Rs and Q_0 are the resonance frequency, the shunt impedance and unloaded Q-value of the acceleration cavity respectively. τ is expressed with the filling time of the cavity t_f and bunch distance t_b as

$$\tau = \frac{t_b}{t_f} \tag{3}$$

$$t_f = \frac{2Q_0}{\omega_0(1+\beta)} \tag{4}$$

where β is the coupling constant of the input coupler. Flat energy multi-bunch electron beam is necessary for multi-pulse inverse Compton scattering [3]. So we have to compensate this effect. We are planning to com-pensate the effect by as adjusting the RF pulse timing.

$$V_{RF} = \frac{2}{1+\beta}\sqrt{\beta R s P_0}\left(1 - e^{-\frac{t}{t_f}}\right) \tag{5}$$

where P_0 is the RF peak power. A numerical calculation of this method is shown in Figure 6 and calculation parameters are shown in Table 3. A red plots is a cavity voltage without beam loading effect. A blue plots shows the acceleration voltage of each electron bunch. Balancing the rising edge of RF and beam loading effect, energy difference in a pulse train is controlled to be 1.9%. If this method is not sufficient, we would consider modulating RF pulse wave shape.

Table 3: Parameters for Beam Loading Effect

Filling time	0.67[μsec]
Bunch distance	8.4[nsec]
RF peak power	10[MW]
Bunch Charge	700[pC]
Number of electron bunches	100bunches/train

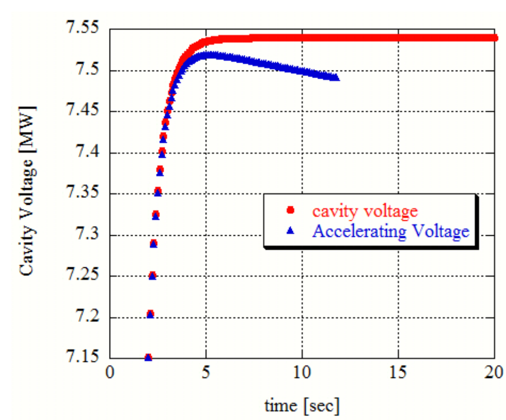


Figure 6: Numerical calculation of beam loading effect.

CONCLUSIONS&FUTURE PLANS

According to our investigation of new design RF-Gun cavity, the Q-value and the shunt impedance improved 20% larger than previous RF-Gun cavity. As a result, reduction in the dark current has been successfully performed, and the electron beam parameters were also confirmed to be better by comparison with previous RF-Gun cavity.

As a future plans, emittance measurement of an electron beam emitted from improved RF-Gun and high quality multi-bunch electron beam generation will be performed.

REFERENCES

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