PRESENT STATUS OF A MULTI -BUNCH ELECTRON BEAM LINAC BASED ON CS-TE PHOTO-CATHODE RF-GUN AT WASEDA UNIVERSITY*

T. Suzuki†, Y. Kato, K. Sakaue, T. Fujino, A. Masuda, A. Murata, M. Washio, RISE, Tokyo, Japan
J. Urakawa, T. Takatomi, N. Terunuma, H. Hayano, KEK, Ibaraki, Japan
S. Kasiwagi, ISIR, Osaka, Japan
R. Kuroda, AIST, Ibaraki, Japan

Abstract

At Waseda university we have been developing a high quality electron generation based on a photo-cathode RF-gun and its application experiments. We have installed a Cs-Te cathode which has higher quantum efficiency and improved RF cavity structure to generate a higher current electron beam. It is expected that the generation of the high charge single bunch electron beam with a low emittance by adopting a Cs-Te cathode can be achieved. Moreover, the generation of high quality multi-bunch electron beam is also expected due to the high quantum efficiency of Cs-Te. We have performed the fundamental studies on single bunch beam generation for understanding the feature of Cs-Te cathode and higher quantum efficiency operation. On the other hand, we have also developed a multi-pulse UV laser for generating the multi-bunch electron beam. Our laser system is composed of all-solid-state Nd:YLF for the stable operation, and the laser is capable to generate a 100 bunch/train with the bunch charge of 800 pC/bunch.

INTRODUCTION

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 tunability of initial beam profile especially for electron bunch length. At Waseda university, we have been developing a high quality electron source based on photo-cathode RF-gun and performing its application experiments, such as pulse radiolysis experiment[1] and inverse Compton X-ray generation. In 2005, we have succeeded in generating soft X-ray via inverse-Compton scattering using Cu cathode RF-gun.[2] The energy of the X-ray generated by our system is within water window region (250-500eV) which can be applied for the soft X-ray microscope for biological observation. We have been improved the system for the better S/N ratio and higher X-ray yield by use of high power laser amplification and collision chamber modification.[3] However X-ray yield of our system was too small to apply for soft X-ray microscope. Therefore, we have improved the RF-gun cavity with a Cs-Te cathode, which has higher quantum efficiency in 2007.[4] Thus, the generation of the low emittance electron beam with higher charge can be realized. Further, the Cs-Te cathode also enables us the multi-bunch electron beam generation. In this paper, the experimental results of the improved RF-gun with Cs-Te cathode and recent progress of the multi-pulse laser system for multi-bunch electron beam generation will be reported.

* Work supported by JSPS Grant-in-Aid for Scientific Research (B) (2) 16340079 and MEXT High Tech Research Project HRC 707
† t-ricky@fuji.waseda.jp

IMPROVED PHOTO-CATHODE RF-GUN

According to the short life time of Cs-Te cathode, a load-lock system has to be installed. In addition, we have improved the structure of the RF cavity in order to reduce dark current and operate at high electrical field. Figure 1 shows the comparison of the photo-cathode RF-gun system between before and after improvement.

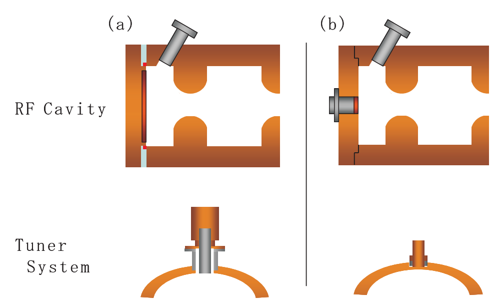

Figure 1: (a)Former Photo-cathode RF-gun system (b)Improved Photo-cathode RF-gun system.

The main improvements were the removal of the Helicoflex seal and the improvement of the tuner system which might lead the electric discharge in RF cavity. By improving of the structure of the RF cavity, the Q value and shunt impedance of the improved RF cavity increased 20% compared with the former RF cavity. [4]

EXPERIMENTS

Charge & Energy Measurement

The experimental setup is described in Fig.2. The UV laser power is regulated by the first half wave plate and the PBS which splits polarized beams into two orthogonal (s-polarized light is reflected at a angle of 90 deg while p-polarized light is transmitted). The spot size and the polarization of UV laser are regulated by optical lens and the second half wave plate, respectively. Figure 3 shows the experimental results of the beam charge and energy measurements produced by each types of the RF-gun. By adopting a Cs-Te cathode and improving a RF cavity, both charge and energy of electron beam were higher than that of the Cu cathode RF-gun.

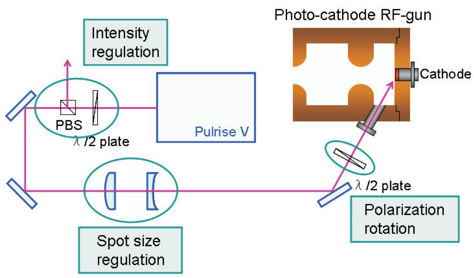

Figure 2: Schematic of Experimental Setup.

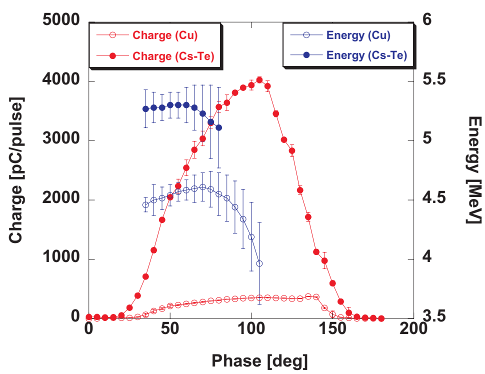

Figure 3: Charge and Energy measurement as a function of laser injection RF phase.

Injection of Polarized Laser

The UV laser is irradiated to cathode in oblique incidence at an angle of about 67.5deg (defined the normal incident as 0deg). One of the merits of oblique incidence is the increase of the quantum efficiency depending on the angle of linear polarization. In this experiment, we have measured the electron beam charge and the reflected laser intensity at each angles of half wave plate. The results were shown in Fig.4 (a) and (b). Figure 4 (b) shows that the quantum efficiency is proportional to the (1-R).

In case of the linear polarized laser incidence to material, the reflectivity depending on the angle of incidence can be determined from the Snell's law (Eq. (1)) and Fresnel's law to p-polarization and s-polarization (Eq. (2)) described below.

$$\theta_2 = \arcsin(\frac{1}{n}\sin\theta_1) \tag{1}$$

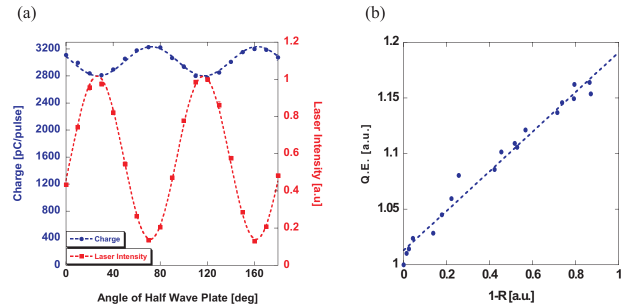

Figure 4: (a)Charge and Laser Intensity as a function of Angle of Half Wave Plate (b) $Q.E. \propto (1-R)$.

$$\begin{aligned} R_p &= \left(\frac{\tan(\theta_1-\theta_2)}{\tan(\theta_1+\theta_2)}\right)^2 \\ R_s &= \left(\frac{\sin(\theta_1-\theta_2)}{\sin(\theta_1+\theta_2)}\right)^2 \end{aligned} \tag{2}$$

where θ_1, θ_2, n and R are the angle of incidence, the angle of refraction, an optical constant of Cs-Te[5] and reflectivity, respectively. Figure 5 shows reflectivity of Cs-Te calculated from Eq.(1) and (2).

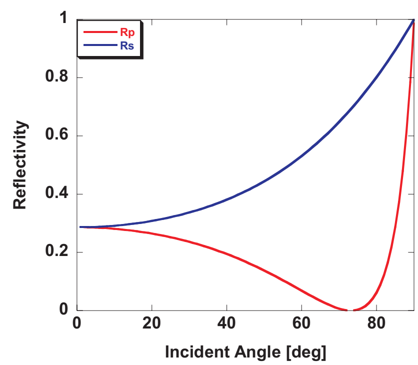

Figure 5: Reflectivity of Cs-Te as a function of Incident Angle.

It shows that the reflectivity of p-polarized laser at the incident angle of about 75deg is nearly 0. The incident angle of about 75deg achieve the highest quantum efficiency as the quantum efficiency was proportional to the (1-R). Therefore, we could confirm that the incident angle of our system is considered to select a suitable angle to take advantage of polarized laser incidence.

Multi-pulse UV Laser System

We have been also developing the multi-bunch electron beam generation system. To generate the multi-bunch electron beam, multi-pulse UV laser to irradiate cathode is required. Thus we have been developing the multi-pulse laser system as a first step. The multi-pulse laser system has designed as shown in Fig.6 and the numerical simulation of LD pumped amplifier has been done in order to have enough gain. Multi-pulse laser system mainly consists of three parts. The first is pulse train picker where pulse train is formed from modelocked pulse laser, the second is LD pumped amplifier, the third is frequency converter where IR laser is converted to UV laser by using two nonlinear crystals (SHG, FHG).

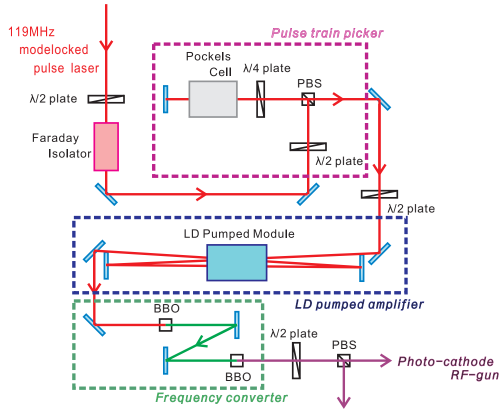

Figure 6: Multi-Pulse Laser System.

To design the specification of LD pumped amplifier which is the very important part in multi-pulse laser system, we have calculated the required gain to obtain the target laser power from the formula described as reference[6]. The required laser power was calculated by the cathode quantum efficiency and a target electron beam charge of 800pC/bunch. Considering the losses in the optics, the required laser power was 3μJ/pulse. Then, we have designed the specification of LD pumped amplifier described as Table.1. The estimated energy of amplified laser pulse after three-pass was about 7μJ/pulse.

Table 1: Parameters to Simulate LD Pumped Amplifier

Lifetime of upper level	520 [μs]
Cross section	1.8×10^{-19} [cm^2]
Effective absorption efficiency	20 [m^{-1}]
Laser wavelength	1047 [nm]
Pump up power	1.142 [kW]
Mean value of pump area	0.32 [cm^2]
Laser spot size	0.283 [mm^2]
Laser rod length	12.6 [cm]
Seed laser power (CW)	200 [mW]

Next, we have actually performed the multi-pulse laser generation with the setup as shown in Fig.6. In this experiment, the pulse train width was set at 200ns (equivalent about 20 pulse/train) as a first step. As a result, we can achieve multi-pulse green laser after first frequency conversion. However multi-pulse UV laser could not be achieved after second frequency conversion because the laser pulse energy was not enough for the forth harmonic generation. To have enough laser intensity for FHG, the more gain in LD pumped amplifier is required. The saturation of gain g depends on the density of laser intensity I_0 described as

$$g = \frac{g_0}{1 + \frac{I_0}{I_s}} \qquad (3)$$

In this experiment, the laser intensity I_0 was exceeded to the saturation intensity of I_s. Therefore, the gain can be increased by expanding the laser spot size before amplification. In near future, we will perform the generation of multi-pulse laser and a multi-bunch electron beam.

CONCLUSIONS & FUTURE PLANS

By adopting a Cs-Te cathode and improving a RF cavity, higher charge and energy of electron beam were successfully achieved. We could confirm that the quantum efficiency was proportional to the (1-R) and the incident angle of our system is a suitable angle to take advantage of linear polarized laser incidence. On the other hand, we also have designed the multi-pulse laser system to generate the multi-bunch electron beam. We have already performed the second harmonic generation with multi-pulse laser but we could not have enough intensity for forth harmonic generation. As a future plans, we will increase the electron bunch charge by reducing the peak electron current compared with space charge limit. Moreover, we will generate multi-pulse forth harmonic and then generate a high quality multi-bunch electron beam.

REFERENCES

[1] A. Fujita, et al., Proc. of PAC'09, TU6PFP027 (2009)

[2] S.Kashiwagi, et al., J. Appl. Phys. 98, 123302 (2005)

[3] K.Sakaue,et al., Radiat. Phys. Chem.77 1136-1141 (2008)

[4] Y.Kato, et al., Proc, of LINAC'08, pp.165-167 (2008)

[5] A.Sugiyama, et al., Proc. of Linac Technology Research Meeting in Japan, FA-3 (2003)

[6] A.Masuda, et al., Proc. of EPAC'08, pp.166-168 (2008)