Performance Study of High Current Photo-Cathode RF-Gun with New Laser System

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Abstract

For sub-picosecond pulse radiolysis project, a new laser system instead of the 10 ps YLF laser was installed to the linac of the University of Tokyo. The new laser system with Ti:Sapphire oscillator (795 nm) and amplifiers generate 300 ps pulses at 10 Hz. The laser is splitted into two beams; the one is compressed to 100 fs (0.15TW) and used for the probe light, while the other is used to drive the RF-Gun. The drive laser is the third harmonics (265 nm, ~ 200 μJ). Moreover, a new 15 MW klystron was installed for the linac RF system. The RF power is divided to the gun and the accelerating section. Finally the time jitter between the electron beam (pump) and the probe laser is designed to be 320 fs (rms). By using the new drive laser system, the charge of 7nC per bunch was observed at the exit of the gun. Improvement of the vacuum in the gun (<10^{-9} Torr) is most effective to obtain the high charge beam. After the two and half years operation of the gun, no degradation of QE has been found for the Cu photo-cathode.

1 INTRODUCTION

A laser photocathode RF electron gun called Gun IV, which was developed by BNL/KEK/SHI international collaboration, was installed to the second line (18L linac) of the S-band twin linac system of Nuclear Engineering Research Laboratory (NERL) of University of Tokyo in 1997 [1]. Since then the behavior and the basic characteristics of the RF-gun had been studied by using Nd:YLF laser [2,3], and the low emittance electron beam (the horizontal : ~1πmm·mrad) was obtained [4].

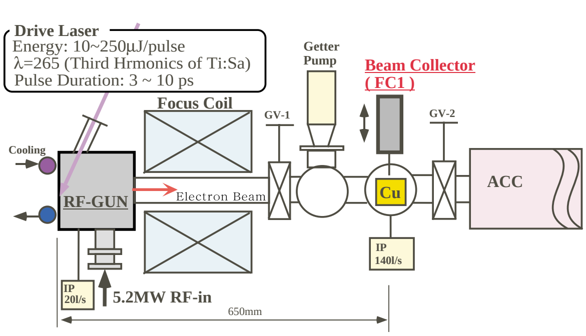

Figure 1: Photocathode RF-gun system

Recently, for the sub-picosecond pulse radiolysis project[5], a new femtosecond T^3 laser system was installed to the 18L linac in order to reduce the timing jitter between the electron beam and the laser pulse. Moreover a advanced 15MW klystron system was installed newly for the linac RF system and the vacuum level was improved.

The performance study of the photocathode RF-gun was done recently under the new systems, and rather high current beam, that is required for the pulse radiolysis experiment, was obtained. The results are reported here.

2 SYSTEM

2.1 Photocathode RF-Gun

A schematic draw of the photocathode RF-gun system is shown in Figure 1. It consists of a 1.6cell RF cavity[6] with a Cu photocathode, a solenoid magnet and diagnostic system with a faraday cup (FC1) and with a beam profiler. The photocathode is illuminated by the drive laser at 68° incident angle. An additional getter pump was installed, then the vacuum was improved (<10^{-9} Torr) even during the RF feeding. For the basic characteristics of the RF-Gun, refer to [1-4].

2.2 New fs T^3 Laser System

Figure 2 shows the whole 18L linac system operated with the new femtosecond T^3 laser system for the sub-picosecond pulse radiolysis. The laser system consists of a Ti:Sa oscillator (795 nm), a stretcher, a regenerative amplifier, a pulse selector and a multi-pass amplifier. It generates 300 ps pulses at 10 Hz as synchronizing with the linac RF. The laser pulse is transported to the linac in 50m vacuum pipe (~10^{-3} Torr), and then splitted into two beams; the one is compressed to 100 fs (0.15 TW) and used for the probe light for the pulse radiolysis analysis and the other is used to drive the RF-Gun. The drive laser is the third harmonics (265 nm, ~ 200 μJ/pulse), and the pulse length is variable from 3 ps to 10 ps. The power fluctuation of the input laser is about 6%.

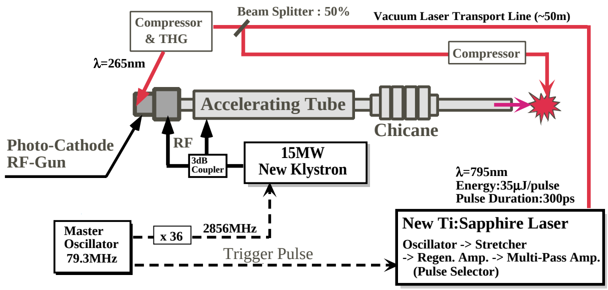

Figure 2: 18L linac system with new laser system for sub-picosecond pulse radiolysis

2.3 New 15MW Klystron System

In the previous system, two 7 MW klystrons have been operated for the RF-Gun and the accelerating tube, respectively. But in the new system a 15 MW klystron feeds RF power to them, so that the synchronization among whole system is improved. And independently, the phase stability is improved by introducing the solid-state RF amplifier including the phase compensation circuit for the input RF to the klystron.

Finally, under the new RF and laser system, the time jitter between the electron beam and the laser pulse is designed to be 320 fs (rms).

3 PERFORMANCE OF THE RF-GUN

3.1 Beam Current Measurement

The bunch charge and the length are measured by using the Faraday cup and the luminescent screen, respectively, at FC1 (See Fig. 1). For the bunch length measurement, the fluorescence at the screen phosphor is measured by the femtosecond streak camera (200fs). The operation parameters of the gun were that the drive laser pulse length is 3~4 ps, the laser spot size on the cathode is ϕ3mm, the input RF power is 5.2 MW (= 85 MV/m gradient) , and that the solenoid magnetic field at the center beam axis is

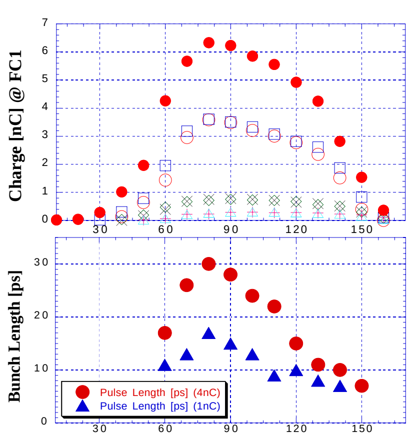

Figure 3: Charge & bunch length vs. phase

1.3k gauss which is optimized to minimize the emittance for the 800 pC bunch [1]. Figure 3 shows the bunch charge and length vs. the relative laser injection phase. Quite high charge bunch (~7 nC) was measured at the exit of the RF-Gun, but the final charge at the end of the linac is less than 2 nC. The charge transmission through the acc. tube was very low. It is found from the figure that the peak phase of the high charge beam is different. from that of the low charge beam (< 1 nC) by 10 deg.

The bunch length was 7ps ~ 30ps. The shorter bunch than 7ps could not be measured due to small amount of fluorescence. It is observed that higher charge bunch is longer, which is due to the space charge effect.

3.2 Quantum Efficiency (QE)

Figure 4 shows the plot of the charge vs. laser energy for different spot sizes of the laser on the cathode. Very high charge beam of 7 nC was obtain at 250 μJ/pulse laser energy, that corresponds to 1.4×10^{-4} quantum efficiency (QE). The highest QE given by the slope of the plot is 1.6×10^{-4}, and the decline of QE can be found at higher laser energy. Fairly high QE was obtained, while the input RF power (or the electric field) is not so high. After the gun had been equipped with the additional getter pump, such high QE was achieved. Thus the improvement of the vacuum in the gun is most effective to for high charge. From the figure, the smaller spot size of the laser gives higher charge, namely higher QE. Such a high QE can attribute to the HIP process of Cu ingot [7].

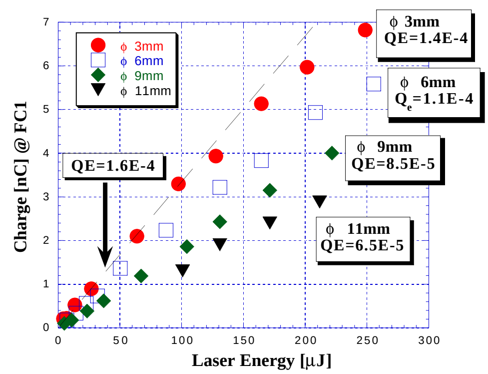

Figure 4: Quantum efficiency for different spot sizes of the laser on the cathode.

3.3 Schottky Effect

As shown in Fig. 5, the Schottky effect [8] was observed by varying the input RF power to the gun. The linearity is obtained in the plot of the square root of

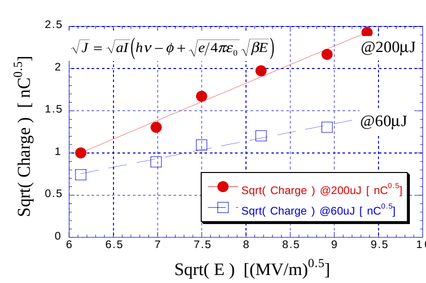

Figure 5: Schottky effect.

charge vs. that of electric field as the formula shown in the figure. The line in the figure indicates just a linear fitting.

3.4 Synchronization with laser pulse

The timing interval between the electron and laser pulse was measured by the femtosecond streak camera at the end of the linac. The electron beam was compressed to the sub-picosecond pulse by the chicane. About 200 data of streak measurements were accumulated and the synchronization between the two pulses was evaluated. Figure 6 shows (a) the data of the timing interval for the fundamental (79.3MHz) and 9th harmonics synchronization at the laser oscillator and (b) the histogram of the latter. The standard deviation from the histogram is 1.9 ps. This mainly comes from the long term temperature drift of the accelerating tube as shown Fig. 6-(a). By eliminating the temperature drift, the timing jitter can be expected to be about 300 fs (rms). Then a new temperature control system of the cooling water was installed. The timing jitter will be measured again later with the new cooling system.

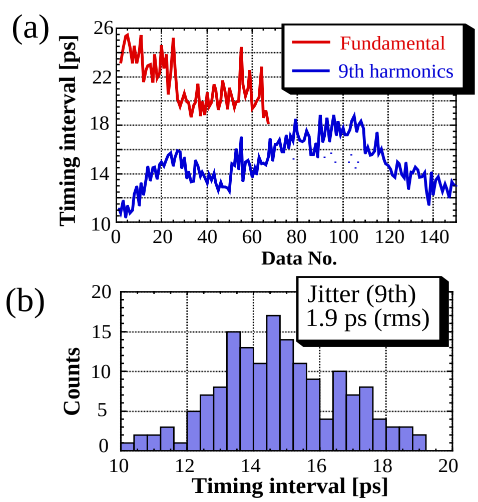

Figure 6: Timing interval between the electron beam and the laser pulse, and the histogram.

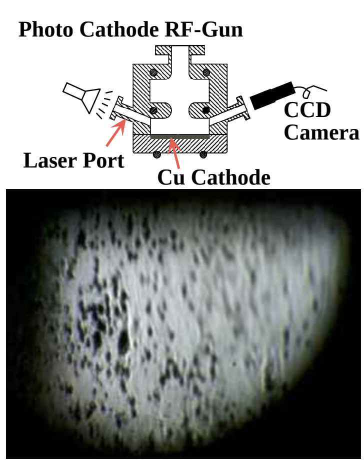

Figure 7: Surface of the Cu photocathode

4 SURFACE OF THE CATHODE

Figure 7 shows picture of the surface of the photocathode which was taken through the laser port from the outside by a microscope CCD camera. Many craters are found on the whole surface. The size of the craters was evaluated roughly to be 0.10~0.25mm. It could be due to the RF discharge before the vacuum improvement [9], but for the details it should be taken out of the gun and investigated more. Although the surface is such rugged, no problem has been found on the operation and performance so far, and the enhancement factor β of the cathode given by the Fowler-Nordheim plot [10] is fair (around typical value) as shown in Figure 8.

5 SUMMARY

The performance test of the photo-cathode RF-gun was done with the new T^3 laser system. High charge beam of 7nC per bunch was obtained from the Cu photo-cathode (HIP) with high QE (1.4×10^{-4}) at 250 μJ laser energy.

The synchronization between the electron and beam is expected to be about 300 fs (rms) by controlling the temperature drift of the accelerating tube.

During the two and half years operation, no degradation of QE has been found for the Cu photo-cathode so far. But the surface of the cathode looks remarkably rugged.

The emittance of the high current beam is under evaluation now. And we are trying to simulate the measurement results by using PALMERA code.

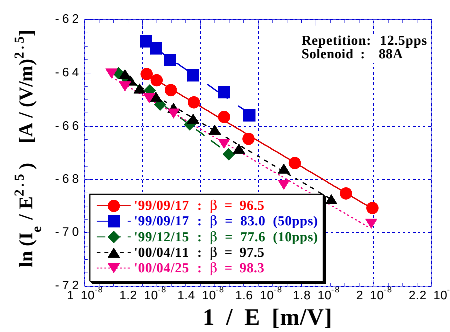

Figure 8: Fowler-Nordheim plot

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