COMMISSIONING A CARTRIDGE-TYPE PHOTOCATHODE RF GUN SYSTEM AT UNIVERSITY OF TOKYO

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Abstract

We have developed a compact-sized cartridge-type photocathode system, which is able to replace a cathode without breaking the vacuum of RF gun to use a high quantum efficiency photocathode. The system consists of a BNL-GUN-IV RF gun, a cathode tube, a feed through and ultra-high vacuum system. The purpose of implementing the system is to increase beam charge for the applications such as pulse radiolysis experiment. We observed the charge of 9 nC from the Cs_2Te cathode. The maximal quantum efficiency of 3.5 % at the charge of 4nC. It was simulated that the quantum efficiency is reduced by the space charge limit, which is caused by reducing electric field of the beam.

INTRODUCTION

The application of ultrafast electron bunches has been an attractive research in the field of electron accelerators. Its remarkable progress of femtosecond bunches generation has made great contributions to many research projects such as X-ray free electron lasers, a high energy linear collider, and ultrafast beam based pump-and -probe analysis.

At the University of Tokyo -Nuclear professional School, we have been conducting picosecond-time-resolved pulse radiolysis and femtosecond laser pump-and-probe analysis, using femtosecond laser and femtosecond electron beam delivered from an S-band linac [1], [2]. The S-band Linac consists of a BNL-GUN-IV 1.6 cell photocathode RF gun, an accelerator tube, transport magnets, and a chicane-type magnetic compressor. The femtosecond electron beam was generated by the photocathode RF gun with Mg cathode, using a 100 fs Ti:Sapphire laser (266 nm, 3rd harmonics), and accelerated up to 18 MeV by the accelerator tube. The electron bunch of 2 nC is compressed by the magnetic compressor up to the bunch width of 440 fs, typically 700 fs (FWHM) [3]. We have achieved 340 fs (short period) and 660 fs (long period) in the synchronization between the probe laser and the pump electron beam [4]. The total time resolution, which is determined by pump beam length, probe beam length of the pump-and-probe analysis, jitter between pump and probe beam, S/N ratio totally, is less than 10 ps and the maximal resolution reaches 4 ps. The time resolution is limited by the S/N ratio of the pump-and-probe, so that we will upgrade the high charge beam as pumping beam for high brightness beam. The QE of our Mg cathode in current use is 1.3×10^{-4}, which is less than that of the Mg cathode at BNL ($1.0\text{-}2.0 \times 10^{-3}$) [5], corresponding to 1/10 as smaller as the expected value currently[6]. We think the reason that Mg cathode was exposed in air or moisture, unfortunately, though we kept it in helium gases immediately after diamond polishing. In the case of high QE cathode such as Cs_2Te, it is indispensable to set up a system in which we can handle a cathode in vacuum throughout the preparation of the cathode, such as a load-lock system with cathode preparation chambers [6], or a cartridge-type photocathode system with a cartridge-type vacuum tube [7-9]. Because of the limitation of the space behind the back plate of the RF gun, the system must be the length within 80 cm. It is suitable to install the compact-sized cartridge-type photocathode system, which fits into the limited space. We report the commissioning of the RF gun with the cartridge-type photocathode system.

EXPERIMENTAL SETUP

The experimental setup for sub-picoseconds pump- and probe-type radiation chemistry is shown in Figure 1. The S-band linac, which provides an electron bunch as a pump-beam, consists of the photocathode RF gun, an accelerating tube and a chicane-type bunch compressor. Driven laser for RF gun and a probe-laser are generated from a Ti:Sapphire oscillator, which produces a laser light with a wavelength of 795 nm, an energy of 35mJ/pulse, a pulse duration of 300 ps and a repetition rate of 10 pps.

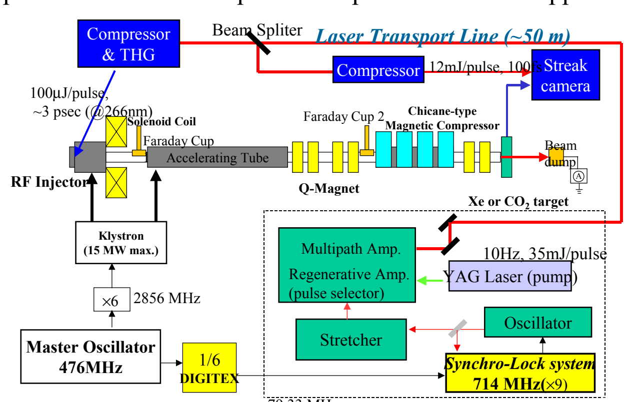

Figure 1: Experimental setup of sub-picosecond pump and probe system.

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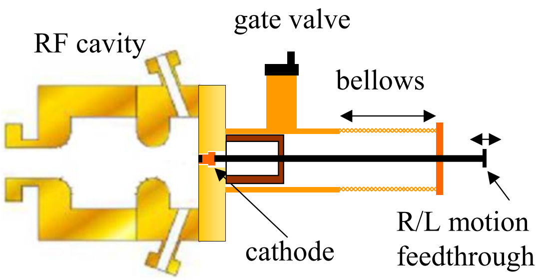

Figure 2: Schematic view of RF cavity with a cartridge-type photocathode system.

The laser and RF pulse of Klystron (and relevant gun and accelerator) are synchronized by using same master Oscillator. The frequency of master Oscillator is 476 MHz, so that we generate sixth harmonic(2856MHz) for the Klystron and sixth sub-harmonic(79.33MHz) for the laser.

The sub-harmonic generator (DIGITEX) also synchronizes detectors or other components. The laser Oscillator is synchronized with the frequency of 714MHz (9th harmonic) and the laser stretches from 100 fs to 300 ps. After stretcher the laser is amplified and retrieved with the frequency of 10 Hz.

In order to achieve good synchronization, we use fs-Ti: Sapphire laser beams which separate to driven laser for RF gun and probe laser: A driven laser is compressed and irradiates to a third harmonic generator (THG), which is provided the third harmonic laser with a wavelength of 265 nm, an energy of ~100 μJ/pulse and pulse duration of a several picosecond. A spot size of the laser on the surface of the cathode is about 3 mm in diameter.

Another laser beam is also compressed to the time duration of 100 fs with the beam energy of several mJ for probing beam.

The total power of RF gun is 15 MW and it is separated a half to RF gun and linac. The pulse length of RF is 2μs with a repetition of 10 Hz. The electron beam generated from the photocathode is focused by solenoid coil(1.0-1.8 kGauss), and a laser injection phase are optimized to charge-maximum.

After accelerating, the beam transports by sets of quadropole magnets and the electron bunch is compressed using the chicane type magnet (see Figure 1). The compressed bunch goes through a chamber filled in Xe or CO2 gas, in which the electron bunch is emitted the Cherenkov light. The bunch duration is observed using a streak camera(FESCA, Hamamatsu Photonics Co.), which is measured the pulse duration of the Cherenkov light. The bunch duration is measured to be 0.7 ps (FWHM). The time jitter between the electron beam and the probe laser reaches 660 fs within the fluctuation of the laser room temperature within 0.1 degree.

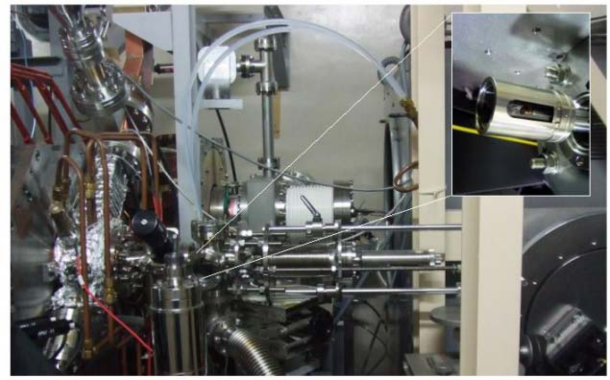

Figure.3 Picture of the system. The cathode is installed into the cartridge case and set at the head of feedthrough.

CARTRIDGE-TYPE CATHODE

We have developed the compact-sized cartridge-type photocathode system in collaboration with Hamamatu Photonics. Figure 2 shows the schematic view of the RF cavity with the cartridge-type photocathode system. The cartridge-type photocathode system is composed of a cartridge-type vacuum tube with a cathode plug, a linear feeder to transport the tube in vacuum, R/L motion feedthrough with a micrometer for fine adjustment, a RF cavity with a back plate that has a centre hole for the replacement of a cathode, and a gate valve between the RF cavity and the linear feeder. Figure 3 is the picture of the system and cartridge case at the head of the feedthrough. The cartridge-type vacuum tube consists of a Mo cathode plug with a cathode surface layer, flanges made of Kovar on the both sides of the tube, and a vacuum bellows to move the cathode plug. A cathode formed on the plug is sealed in the vacuum tube. The diameter of the plug is 7.2 mm. Vacuum tubes are produced in a factory and the tubes of high QE cathode are selected from these tubes. The vacuum tube is set in the linear feeder and transported to the back plate. A pair of cutters before the back plate cut the Kovar foil and then the cathode is inserted into the hole. While exchanging the cathode, the RF cavity is not exposed to ambient air, since the gate valve between the RF cavity and the linear feeder is closed. The cartridge-type photocathode system is very useful for the performance test of cathode because of the easiness of exchanging the cathode. In order to operate Cs2Te cathode, ultra-high vacuum pressure must be necessary and we obtain lower than 10-9 Torr using an ion pump and two getter-pump.

EXPERIMENTAL RESULTS

Figure 4 shows the charge after the RF gun vs. the laser power. The line means the charge of QE of 3.5%, corresponding to the QE when the laser power is 0.6μJ. The charge is saturated than 7 nC. We can obtain the charge from Cs2Te, corresponding to 100 times than the power of Mg cathode (when the laser power is 100μJ, it reaches 3nC). The quantum efficiency can be written

$$QE(\%) = \frac{1.23\times 10^{2}}{W(\mu J)\lambda(nm)}Q(nC)$$.

Figure 5 shows the charge vs the laser power. We observe the reduction of the QE when the laser power increases.

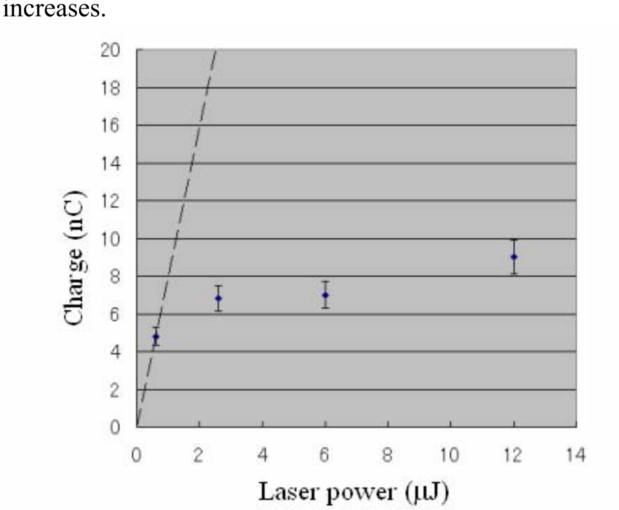

Figure 4: Charge vs laser power. The line is estimated the same QE of 3.5%.

The charge after acceleration is 4 nC (at Faraday cup 2 in figure 1) when the charge before acceleration is 6 nC. By PALMERA simulation, emittance growth is observed at the laser pulse duration of 1.5 nC.

DISCUSSION

There is the problem of the space charge which electronic oneself makes which occurred from a cathode when electric charge is large. Space charge causes the reduction of electric fields of an opposite direction by a reflected image electric charge on the cathode side with an acceleration electric field by a high frequency. As for the influence to a cathode by this space charge, we consider these two actions – cancellation of Schottky effect by an acceleration electric field, screening the electric field for the following electron by the electron upon the surface. In the simulation, we calculate to decrease the QE of the cathode using reduced electric field by space charge and Schottky effect.

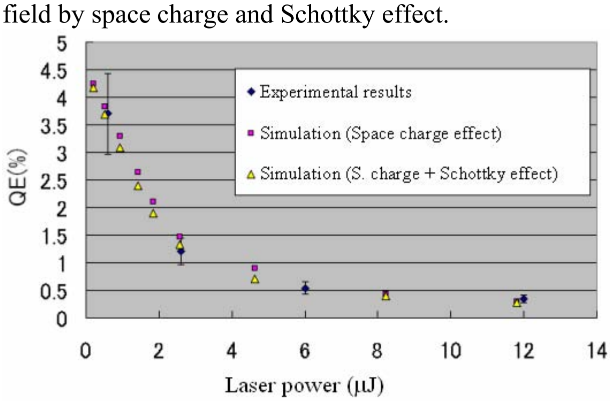

Figure 5: Charge vs laser power. The line is estimated the same QE of 3.5%.

The quantum efficiency including deacceleration effect is described as

$$QE = A\left[h\nu - \left(\phi - \sqrt{\frac{e(E_{acc} - E_{dec})}{4\pi\varepsilon_0}}\right)\right]^2.$$

Here A is constant by surface condition, ϕ is work function of the cathode material, E_{acc} is RF accelerated field, and E_{dec}: deaccelerated filed by space charge.

The value of laser power 4.66eV, work function of Cs_2Te 3.5eV, accelerating field 100MV/m, respectively is used.

We divide a direction in time and consider that the electrons until t_k effect the electrons in the time range t_{k+1}. The value of QE_0 is the initial quantum efficiency. We estimate the charges at t_k if the space charge would be neglect, then the disaccelerated electric field are estimated. The total QE can be written in

$$QE_t = QE_0 \cdot \frac{\sum \Delta q_{(k)}(E_{acc} - E_{dec(k-1)})/E_{acc}}{\sum \Delta q_{(k)}}.$$

The estimated value of QE by each laser power also shows in Figure 5. We found that it is good agreement with experimental data.

CONCULSION

We developed the compact-sized cartridge-type photocathode system, which is able to replace a cathode without breaking the vacuum of RF gun to use a high quantum efficiency photocathode. We observed the charge of 9 nC from the Cs_2Te cathode, and the quantum efficiency of 3.5 % at the charge of 4nC. It was simulated that the QE is reduced by the space charge limit that is caused by reducing electric field of the beam.

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