MG CATHODE S-BAND RF GUN/LINAC FOR RADIATION CHEMISTRY RESEARCH

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Abstract

Aiming to generate a electron bunch with tens nC, a Mg photocathode RF gun, which was manufactured especially by precise machining and diamond polishing in order to decrease a dark current, had been constructed and installed to an S-band linac at Nuclear Engineering Research Laboratory, University of Tokyo. The S-band linac system is utilized for a pulse radiolysis with a femtosecond laser. Quantum efficiency of the Mg cathode was measured to be 1.3×10^{-4} before laser cleaning. A timing jitter between a pump-beam and probe-laser was reduced due to improvement of an air conditioner in the linac building. The jitter was measured to be 1.4 ps (rms) for a hour.

1 INTRODUCTION

A pulse radiolysis method is a useful and powerful technique for studying chemical reactions. At Nuclear Engineering Research Laboratory, University of Tokyo, intensive researches using the pulse radiolysis method have been carried out not only in aqueous solutions but also in organic liquids and polymeric systems [1]. Especially, the chemical reactions of hot, room temperature and critical water in a time range of picosecond and sub-picosecond are interesting phenomena.

The pulse radiolysis method in the ultra-short-time range has been realized by short bunch electron(e^-)-beam from a S-band linac and a femtosecond laser. The S-band linac consists of a photocathode RF gun, an accelerating tube and a chicane-type bunch compressor as shown in Fig. 1. Driven laser for the RF gun and a probe-laser are generated from a Ti:Sapphire laser, which produces a laser light with wavelength of 795 nm, energy of 30mJ/pulse, pulse duration of 300 ps and repetition rate of 10 pps. The laser light is guided in vacuum chambers, whose length is approximately 50 m, connected by bellows. The laser light is split in order to realize precise synchronization between a pump-beam and the probe-laser. One laser light is compressed into the pulse width of 100 fs, and used as the probe-laser. The other is guided to a third harmonic generator, which is provided the driven laser with wavelength of 265 nm, energy of a few hundred μJ/pulse and pulse duration of a several picosecond.

So far, a Cu was used as the photocathode of RF gun [2,3]. Although a performance of the Cu photocathode RF gun was achieved, various stabilities have to be improved. For example, it was difficult to provide a few nC high charge with sub-picosecond bunch width. The beam with the charge of less than 1 nC/bunch and the bunch width of larger than 1 ps was generated stably. In this case, the signal-to-noise ratio for the pomp-and-probe experiment was not enough. The synchronization should be stable for the longer time to accomplish the chemical reaction of the water experiment. For that reason, we started to construct a new RF gun with Mg photocathode. A quantum efficiency (QE) of the Mg, which is in the order of 10^{-3}, is 10 times larger than one of Cu, so that dense electron bunch is able to be produced. In addition, we have improved an air conditioner in the linac building, because the instability of the synchronization was caused by a fluctuation of temperature in the building. The fluctuation of temperature after the improvement is ± 0.5 $^{\circ}$C compared with before the improvement (± 3 $^{\circ}$C).
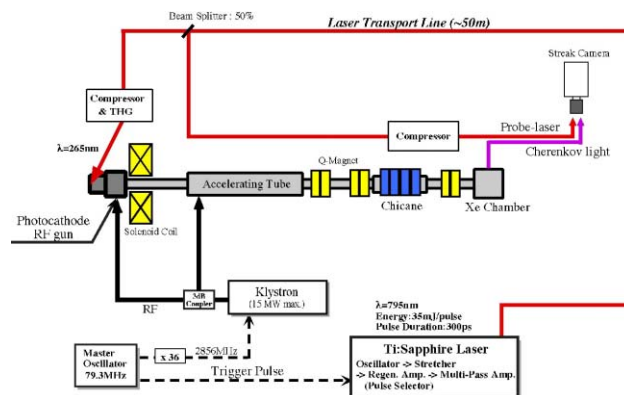

Figure.1:S-band linac system for pulse radiolysis in ultra-short-time range.

2 MG PHOTOCATHODE RF GUN

2.1 RF gun cavity

The Mg photocathode RF gun (BNL Gun-IV type) had been constructed in cooperation with SPring-8, KEK, SHI, Waseda University and BNL. To decrease a dark current, the inner wall of the cavity was diamond-precise machined and the cathode plate was polished using diamond powders whose sizes were 3μm and 1μm in diameter. Roughness of the cavity wall and the cathode plate are tens nanometer and less than 1 μm respectively. The gun was baked for 7 days at 150 ^{o}C and 48 hours at 120 ^{o}C before and after installation to the linac. A vacuum condition is kept to be less than 5×10^{-10} Torr during gun operation. The aging of the gun was carried out carefully for 528 hours (22 days). Figure 2 shows the Fowler-Nordheim plot. Each point indicates the measured value after each aging term (triangle points indicate after 336 hours, squares after 413 hours and circles 528 hours). The enhancement factor β calculated by the fitting are 48, 36 and 20, respectively. In case of the Cu cathode, the quantity of β was typically 80-100. The dark current was measured to be 600 pC/pulse for RF power of 6.6 MW, pulse width of 2 μs and repetition rate of 10 pps.
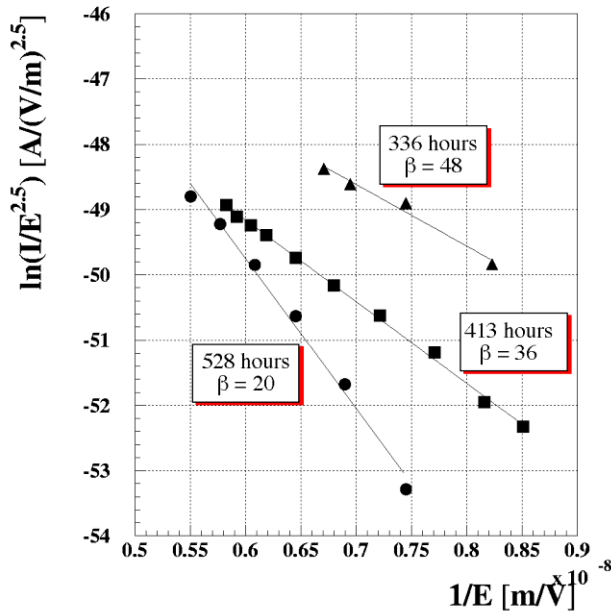

Figure 2: Fowler-Nordhiem plot for each aging term.

2.2 Quantum Efficiency

The charge from the RF gun was measured using the Faraday cup set downstream of a solenoid coil (see Fig. 1). The charge as a function of the driven laser energy is shown as Fig. 3. During the measurement, the RF power is 6.6 MW, the RF pulse width 2 μs, the repetition rate 10 pps and a spot size of the laser larger than 3 mm in diameter. Magnitude of the solenoid coil, which is in the range of 1.0-1.8 kGauss, and laser injection phase for the cathode were optimized to charge-maximum. A dash line as shown in Fig. 3 is a fitting result of QE, where 5 points up to 100 μJ/pulse are used for fitting. The QE is calculated to be 1.3×10^{-4}, which is as same as that of Cu (1.6×10^{-4}). Generally the QE of the Mg without a treatment for the surface, such as the laser cleaning, is in the order of 10^{-5} due to the oxide-layer on the surface [4]. Our Mg cathode was kept in Helium gases immediately after diamond polishing, and the cathode was in the air for almost 2 days for installation. Therefore, we may consider that QE is higher owing to few oxide-layer. However, it is 1/10 as smaller as the expected value currently.

QE looks saturated over 3 nC/bunch. Distance between the end of solenoid coil and the Faraday cup is about 50 cm and this drift space has 2 cm in diameter. Consequently the high charge may be cut off by the beam duct.
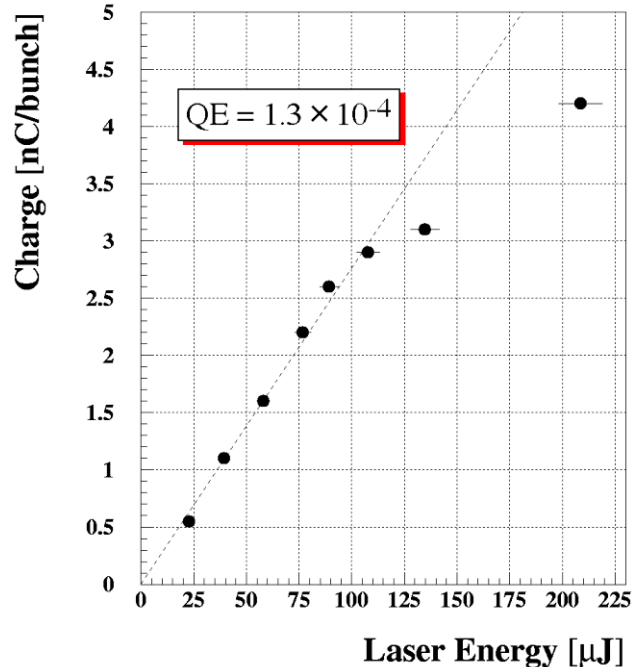

Figure 3: Charge as a function of the laser energy.

2.3 Electron Beam

Energy of the electron beam was measured using a magnetic analyzer. The energy was 22 MeV. Normalized emittance (rms) was measured by the quad scanning method at downstream of the accelerating tube. The results were obtained to be approximately horizontal emittance of 80 πmm-mrad and vertical emittance of 40 πmm-mrad. On this occasion, the charge was 2 nC/bunch and the bunch width was approximately 10 ps (FWHM). Now we don't conclude a reason of such high emittance, but we may consider that a bad shape of the laser profile, which is not Gaussian, makes the emittance grow [5]. As

a result of compressed bunch, we obtained to be 0.7 ps (FWHM) [6].

3 SYNCHRONIZATION EXPERIMENT

The synchronization experiment was performed to set a Xe chamber at the end of the chicane-type bunch compressor. Cherenkov light emitted from the chamber is guided to a streak camera with the probe-laser as shown in Fig.1. At first, we considered that the laser transport line had to be kept on vacuum, because the laser light was scattered by the air. However, the transport line kept on vacuum was twisted by external pressure. Especially the strain at the bellows dominantly causes a fluctuation of the path length of transport line. Consequently, the timing drift and jitter occur. Therefore, the transport line was fill with Nitrogen gass. Figure 4 shows a result of the synchronization test. The e^--beam parameters were the charge of 1nC/bunch and the bunch width of 1.6 ps (FWHM). Although a little of timing drift remains at the start and end of data taking, the timing jitter was measured to be 1.6 ps (rms) for 2 hours and 1.4 ps (rms) for 1 hour between 20:30 and 21:30 as shown in Fig.4. In the case of the vacuum, the synchronization can be measured for only one hour due to the timing drift with a long-time period. The time-interval between the pump-beam and probe-laser was longer than 16 ps at peak-to-peak.

4 CONCLUSION AND DISCUSSION

The Mg photocathode RF gun, which is performed precise machining and diamond polishing in order to decrease the dark current, had been constructed and installed to the S-band linac. QE of the Mg cathode was measured to be 1.3×10^{-4}, before laser cleaning. However, we wish to generate higher charge beam as tens nC/bunch. The energy of 22 MeV, the horizontal emittance of 80 πmm-mrad, the vertical emittance of 40 πmm-mrad and the bunch width of 0.7 ps were measured.

The synchronization had been improved to be 1.4 ps for an hour. It is advanced for the chemical reactions experiment that the timing drift with long-time period was reduced much. However, to realize the time resolution of sub-picosecond, the timing jitter has to be decreased more. Now we are researching a primary factor for the jitter.

To attain the dense e^- bunch due to high QE of the Mg cathode, the laser cleaning system has to be adopted. Therefore, we are investigating the cleaning system and the optics. The pump-and-probe experiment for the chemical reaction in water has started.

5 REFERENCES

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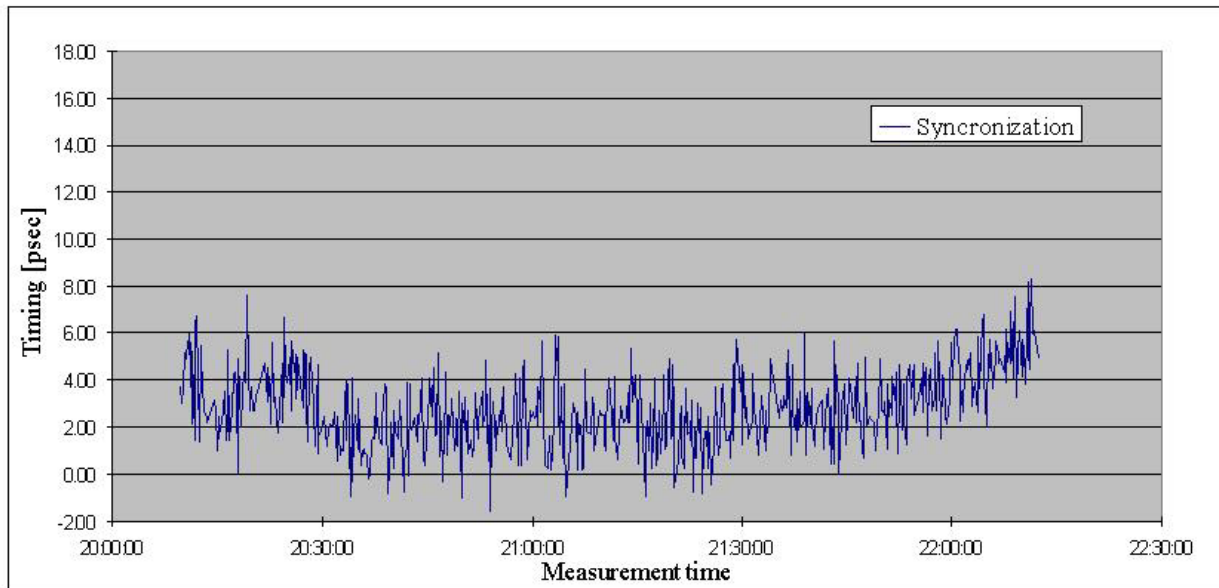
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Figure 4: Synchronization result. Horizontal axis indicates the time-interval between the pump-beam and probe-laser.