The 14th Symposium on Accelerator Science and Technology, Tsukuba, Japan, November 2003

STATUS OF S-BAND FEMTOSECOND LINEAR ACCELERATOR IN OSAKA UNIVERSITY

J. Yang#, H. Tomosada, K. Takeya, T. Yamamoto, T. Kozawa, Y. Honda, Y. Yoshida, S. Tagawa
The Institute of Scientific and Industrial Research, Osaka University,
8-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan

Abstract

A new S-band femtosecond electron linear accelerator was developed in Osaka University for the study of radiation-induced ultrafast physical and chemical reactions in femtosecond time regions. The femtosecond electron accelerator was constructed with a laser driven photocathode RF gun, a linear accelerator (linac) and a magnetic pulse compressor. The electron pulse produced from the photocathode RF gun was accelerated by the linac with energy modulation and compressed into a few tens femtosecond by the pulse compressor. The femtosecond electron pulse is expected for the study of ultrafast phenomena by means of pulse-radiolysis with a femtosecond laser light.

INTRODUCTION

Development of a pump-probe measurement technique in the femtosecond or attosecond scale is important for the study of a dynamic process involving the mechanical motion of electrons and atomic nuclei in physics, chemistry and biology. A pulseradiolysis, which is pumped by an ultrashort electron beam and probed by an ultrashort light, is a powerful tool for the observation of ultrafast radiation-induced phenomena, such as ionization, excitation, relaxation, electron transformation and so on.

The time resolution of the pulse radiolysis has reached to picosecond by using a picosecond electron pulse. In Osaka University, a subpicosecond pulse radiolysis with a time resolution of 800 fs was developed by using a femtosecond electron pulse produced in an L-band linear accelerator, a probe femtosecond laser light, and the time jitter compensation between the electron pulse and the laser light[1,2]. Recently, a new femtosecond pulse-radiolysis system with a time resolution of <100fs was developed in Osaka University.

However, in order to achieve such time resolution, the developments of the three technologies are required: (1)a femtosecond electron pulse, (2)a probe femtosecond light source, and (3)precise synchronization between the electron pulse and the probe light. To solve these problems, a laser-driven photocathode RF gun based linear accelerator was constructed to produce such short electron pulse. It was known that the efficiency of charged particle pulse compression depends on the beam quality. The photocathode RF gun produces a low emittance short-bunch electron beam, such as <1 πmm-mrad at 3 ps[3,4], resulting in an effective pulse compression into femtosecond. Another advantage by using the RF gun is easy to synchronize the probe laser light with the electron pulse.

EXPERIMENTAL ARRANGEMENT

Photocathode RF Gun and Laser

Figure 1 shows the new femtosecond pulseradiolysis system. A 1.6-cell S-band (2856MHz) RF gun, produced by Sumitomo Heavy Industries (SHI)[3,4], was used in the system. The RF gun was composed of two cells: a half cell and a full cell. The length of the half cell was designed to be 0.6 times the full cell length to reduce the beam divergence. The coupling between the waveguide and cavity was located in the full cell. Coupling between the cells was accomplished via the iris of the cavity. The copper cathode used in the system was located on the side of the half cell. A single solenoid magnet was mounted at the exit of the RF gun to compensate the space charge emittance. The cathode magnetic field was measured to be less than 10G at a peak magnetic field of 3kG, resulting in a negligible emittance growth due to the cathode magnetic field.

The RF gun was driven by an all solid-state LD-pumped Nd:YLF picosecond laser. The laser consisted of a laser oscillator, a regenerative amplifier, and a frequency converter. The oscillator was mode-locked with a frequency of 79.3MHz, the 36th sub-harmonic of the 2856MHz accelerating RF, by adjusting the cavity length of the oscillator with a semiconductor saturable absorber mirror (SESAM). The time jitter between the oscillator output and the reference 79.3 MHz RF signal was measured to be <0.5 ps using a phase detector technique. After the oscillator, a Pockels cell captured a single oscillator laser pulse to amplify the pulse energy up to about 2 mJ in the regenerative amplifier. The repetition rate of the regenerative amplifier is 30 Hz in the maximum. The amplified pulse was frequency quadrupled to a 262 nm ultraviolet (UV) light with maximum pulse energy of 300 μJ using a pair of nonlinear crystals. The UV light was injected on the cathode surface at an incident angle of approximately 2° along the direction of the electron beam using a prism placed downstream of the gun, as shown in Fig.1.

Linear Accelerator and RF source

The electron beam produced by the RF gun was accelerated with a 2 m long S-band travelling-wave linear accelerator (linac). The linac was located at a distance of 1.2m from the cathode surface. The energy of the electron pulse was also modulated by adjusted the RF phase for

---

#yang@sanken.osaka-u.ac.jp

pulse compression, as described below. The operating temperatures of the RF gun and the linac were 32°C and 30°C, respectively. The temperature fluctuation of both the RF gun and the linac were within 0.1°C.

The peak RF inputs of the RF gun and the linac were 10 MW and 30 MW, respectively, which was produced by a 40 MW Klystron. The stability of the RF power was 0.1% peak-to-peak. The effective pulse width of the RF was 4μs. The peak on-axis electric fields in the RF gun and the linac were approximately 100 and 20 MV/m, respectively. The repetition rate of the operation was 10 Hz in the experiment. A high-power phase shifter installed in a 30 MW RF line, as shown in Fig. 1, was used to adjust the RF phase of the linac for energy modulation.

Magnetic Pulse Compressor

The magnetic pulse compression, which was constructed with two 45°-bending magnets and four quadrupole magnets, is a technique to longitudinally focus a charged beam by rotating the phase space distribution in a magnetic field. The picosecond electron pulse generated in the RF gun and accelerated in the linac with energy was compressed into femtosecond by adjusted the magnetic fields of the quadrupole magnets. However, it is noted that, in order to obtain a femtosecond electron pulse, the generation of a low-emittance electron beam should be important in the system.

Femtosecond Pulse Radiolysis System

A new pulseradiolysis based an S-band photocathode femtosecond linac is shown in Fig.1. The compressed femtosecond electron pulse was used as an irradiation source, while a mode-locked Ti:Sapphire femtosecond laser was used as a probe light source. The Ti:Sapphire laser oscillator output was phase-locked with the 79.3 MHz RF (the 36th sub-harmonic of the 2856MHz accelerating RF). The femtosecond oscillator light was stretched to 200ps by a pulse stretcher, and amplified the pulse energy up to about 1 mJ in a regenerative amplifier with a Pockels cell. The repetition rate of the regenerative amplifier is 1 KHz. An optical parametric amplifier (OPA) was located at exit of the regenerative amplifier. The probe light wavelength from 300nm to 1200nm can be selected by changing BBO crystals for applications.

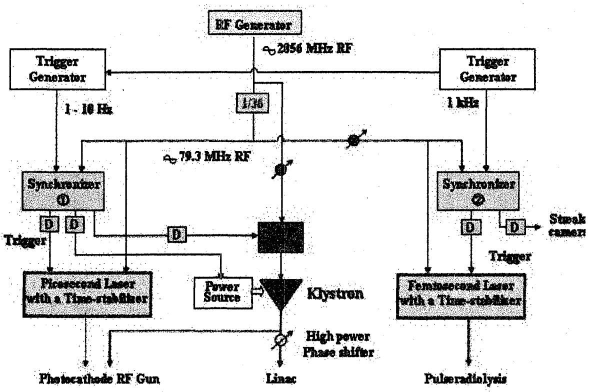

Fig. 2 Time synchronization between the lasers and RF

However, the time jitter between the electron pulse and the probe femtosecond laser was occurred in the system due to the stabilities of the accelerating RF source and the laser oscillator. In order to obtain a femtosecond time resolution in the pump-probe measurement, a jitter compensation technique was used. The time interval of a Cherenkov light emitted from the electron pulse and the probe laser light is measured precisely by a femtosecond streak camera. The data is used to compensate the effect of the time jitter with shot-by-shot in the pump-probe measurement.

Finally, in the femtosecond pulseradiolysis system, the time resolution is limited by the degradation of velocity difference between the electron and the laser light in samples. The use of a thin sample leads to a higher time-resolution, but the S/N ratio would be decreased in the measurement. An oblique incidence of the probe light was considered in the system[5].

Timing Synchronization

Figure 2 shows a block diagram of the timing synchronization system for the pulseradiolysis. A RF signal

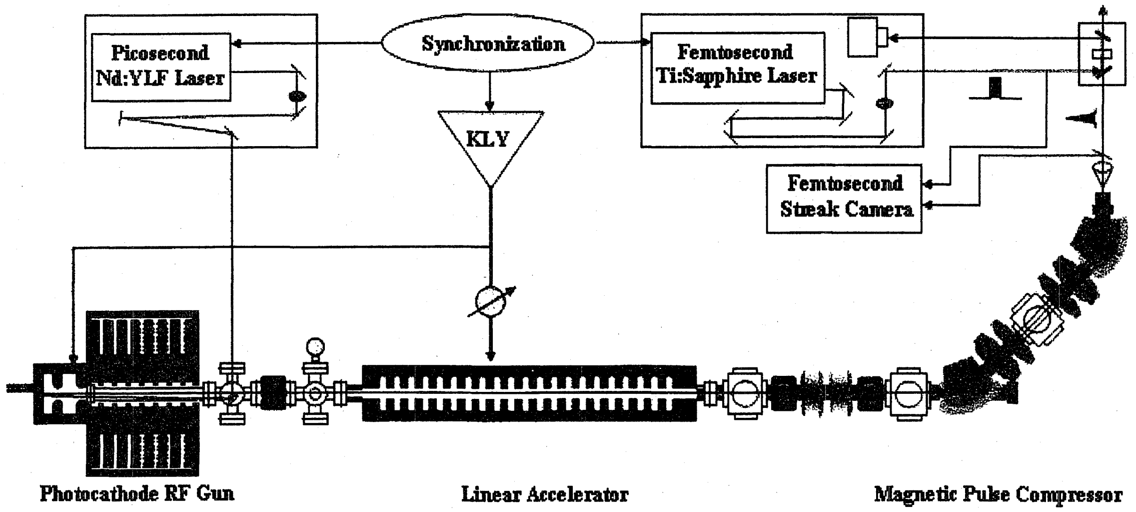

Fig. 1 A femtosecond electron linac and a femtosecond pulseradiolysis

generator supplies a 2856 MHz radio frequency. The RF signal was divided into two: one was used to drive the Klystron, while another is divided in frequency by 36 to 79.3 MHz to drive both the picosecond Nd:YLF laser and the femtosecond Ti:Sapphire laser. A trigger signal generator generates two 1 KHz signals: one is synchronized with the 79.3 MHz RF signal and used for the Ti:Sapphire laser and measurement system (such as a streak camera), while another is divided to a 10 Hz trigger signal and used for the trigger signals of both the Nd:YLF laser and Klystron. Two low-power phase shifters installed in the 79.3 MHz RF lines are used to adjust both the laser injection phase in the RF gun and the timing of the probe femtosecond laser light. The timing jitter between the electron pulse and the laser light is expected to be a few hundreds femtosecond.

Accelerator Control System

The reappearances and the stabilities of both the electron beam and the laser light are important in the pump-probe measurement. An accelerator control system by using a programmable language controller (PLC) technique[6] was developed. All magnetic fields of the magnets and the laser ON/OFF are controlled by a personal computer (PC). All parameters after optimization are automatically saved into the memory of the PC for the next experiment.

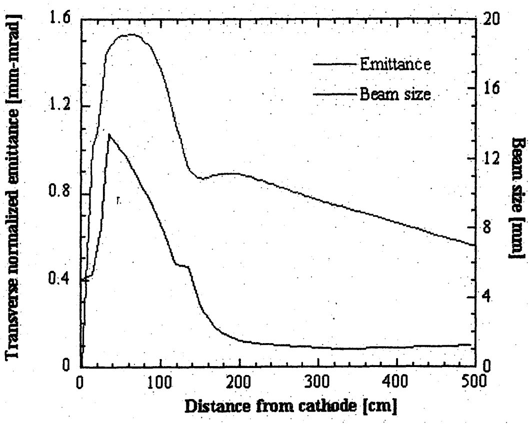

Fig. 3 The calculated emittance and beam size

SIMULATIONS

The generation and acceleration of the electron pulse in the RF gun and the linac were simulated by using PARMELA code with a 3D particle-to-particle space-charge calculation. Figure 3 shows the results of the phase-space distributions of the electron beam versus the distance from the cathode. In the simulation, the charge of the electron pulse was fixed to be 0.1 nC. The laser injection phase in the RF gun was 30° from the zero crossing of the RF. The solenoid field was 1.2kG, which was given the best emittance compensation at the bunch charge of 0.1 nC. The RF phase of the linac was 70° to give an optimum energy modulation for the pulse compression. The beam energy was 20 MeV. The simulation indicates that an electron beam at the exit of the linac with a transverse normalized emittance of 0.7 πmm-mrad, a longitudinal emittance of 15 KeV-deg and an energy spread of 3-4 % can be achieved at the bunch charge of 0.1 nC.

By using the output of the PARMELA simulation, we calculated the pulse length of the electrons passing through the magnetic pulse compressor by using TRACE-3D code. By optimising the magnetic fields of four quadrupole, we obtained the compressed pulse length of the electrons as a function of the bunch charge, as shown in Fig. 4. The data indicated that the minimum rms pulse length of 20 fs is achieved at the bunch charge of <0.2 nC. The pulse length of the electrons increases for the high charge, 130 fs for 1.0 nC.

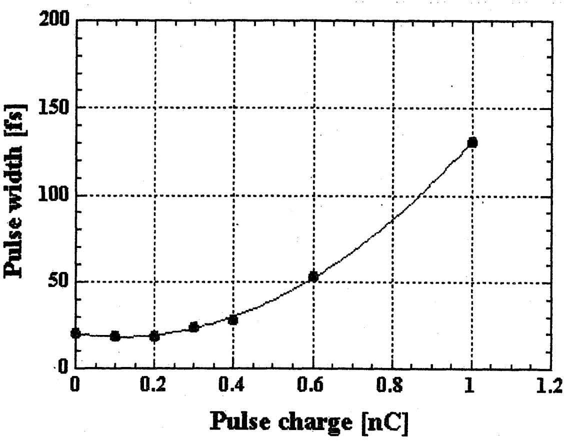

Fig. 4 The calculated pulse length versus bunch charge

CONCLUSIONS

A new S-band femtosecond electron linear accelerator based a laser-driven photocathode RF gun was developed. A femtosecond pulseradiolysis system was constructed with a femtosecond laser light and expected for the study of radiation-induced physical and chemical reactions in femtosecond time regions.

A simulation with beam acceleration and magnetic pulse compression was presented. The simulation of the pulse compression was done with a linear space-charge effect. However, the effects of high-order space-charge effects and coherent synchrotron radiation should be considered in the next step for producing an electron pulse in a few femtosecond or attosecond.

REFERENCES

[1] Y. Yoshida, et al., Radit. Phys. Chem., **60** (2001), 313-318..
[2] K. Kozawa, et al., Nucl. Instrum. Meth. A **440** (2000), 251-254.
[3] J. Yang, et al., J. Appl. Phys., **92** (2002), 1608-1612.
[4] J. Yang, et al., Nucl. Instrum. Meth. A **491** (2002), 15-22.
[5] H. Tomasada, et al., Proc. of this conference.
[6] K. Takeya, et al., Proc. of this conference.