DEVELOPMENT OF DOUBLE-DECKER ELECTRON BEAM ACCELERATOR FOR FEMTO/ATTOSECOND PULSE RADIOLYSIS

Y. Kuroda#, J. Yang, T. Kondoh, A. Yoshida, Y. Yoshida, The Institute of Scientific and Industrial Research, Osaka University, 8-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan

Abstract

A concept of double-decker electron beams, which have vertically different positions and time delay, was proposed for study of ultra-fast electron-induced reactions or phenomena by pulse radiolysis technique. One of the double-decker electron beams is used as a pump source, and another is converted to Cherenkov light and used as a probe light source. The double-decker electron beams were generated successfully by injecting two Nd:YLF picosecond laser beams into a photocathode RF gun. The beams were accelerated up to 31MeV by an S-band booster linear accelerator and compressed by a magnetic bunch compressor into femtosecond. The profiles of the double-decker electron beams were measured at the exits of the RF gun, the linac and the bunch compressor. The normalized transverse emittances of both beams were obtained to be 3.3mm-mrad for the upper beam and 6.4mm-mrad for the lower beam at bunch charge of 2nC. The relative energy spread was obtained to be 0.1~0.2% for both beams.

INTRODUCTION

Study of the electron-induced reactions or phenomena in femto/attosecond time region is very important to use electron beams for industrial applications. For example, in the nanofabrication of semiconductors, the accuracy of process depends on the size of spur in which the ultra-fast reactions are occurred. Pulse radiolysis is a powerful tool to study the ultra-fast reactions in spur. In the pulse radiolysis, a short-bunch electron beam is used as a pump source, while a synchronized laser light is used as a probe source.

The first experiment of pulse radiolysis was carried out in Tront University in 1969. In their system, the electron beam, which was generated by an S-band linear accelerator (linac), was used as the pump beam. The Cherenkov light emitted from the electron beam was used as the probe light. A time resolution of ~20ps was achieved.

After Tront experiment, the time resolution of pulse radiolysis has been improved <1ps in Osaka University by using femtosecond electron beam and laser light. However, the reactions in spur take place earlier than 100fs. To study the reactions, a femto/atto second pulse radiolysis is necessary.

The time resolution of pulse radiolysis is determined by four factors:

$$\Delta t = \sqrt{t_e^{\,2} + t_l^{\,2} + t_j^{\,2} + g_{(L)}^{\,2}}, \qquad (1)$$

#kuroda81@sanken.osaka-u.ac.jp

where, t_e is the electron bunch length, t_l is the probe light pulse width, t_j is time jitter between the electron beam and the probe light pulse, and $g_{(L)}$ is the deterioration of time resolution caused by the difference of velocity of the electron and light in a sample due to refractive index.

The electron bunch length can be compressed into femtosecond by optimization of the magnetic bunch compressor. The deterioration of time resolution will be avoided by an equivalent velocity method. In Osaka University, a 98-fs electron single bunch at charge of 0.17nC was successfully generated by using a photocathode RF gun and a magnetic bunch compressor. The electron bunch was also successfully used to improve the time resolution of pulse radiolysis with the equivalent velocity method. However, to improve the femtosecond time resolution, the time jitter should be reduced.

In order to reduce the time jitter between the electron bunch and the probe light, a new concept of double-decker electron beams were generated with a photo cathode RF gun by injecting two laser beams on the cathode. One of the double-decker electron beams were used as the pump source, while another was used as the probe source by Cherenkov radiation. Therefore, the time jitter between the electron beam and the probe light can be extremely reduced by stabilizing the accelerating RF.

EXPERIMENTAL ARRANGEMENT

Figure1 shows the concept of the double-decker electron beam accelerator. The upper beam (back beam) was used as the pump beam. The lower beam (front beam) was used to convert Cherenkov light as the probe light.

The experimental arrangement is given Fig. 2 The double-decker electron beam accelerator was constructed with a photocathode RF gun, a picosecond laser, a booster linear accelerator and a magnetic bunch compressor.

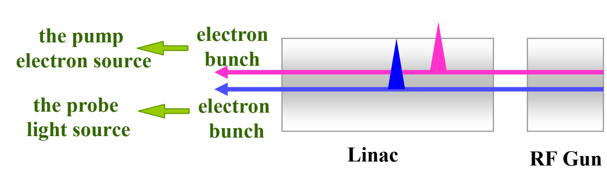

Figure 1: Concept of the double-decker electron beams.

Photocathode RF Gun

A 1.6 cell S-band (2856MHz) photocathode RF gun as Gun 4 type at BNL system was used. It was constructed by a half cell and a full cell. The material of cathode was copper. The length of half cell was 0.6 times of full cell. A solenoid magnet was assembled at the exit of RF gun to compensate the space-charge-induced emittance of the beams. The two electron beams were generated in a horizontal position on a cathode. The solenoid magnet rotates their positions into vertical position because the magnetic field on the cathode was not zero.

Picosecond Laser and Injection System

An Nd:YLF picosecond laser was used to drive the photocathode RF gun. In order to generate the double-decker electron beams, the output of the Nd:YLF picosecond laser was divided by a beam splitter into two laser beams. One was passed through an optical delay which constructed a parallel movable stage. To accelerate the double-decker electron beams with same RF phase, the time interval of the two laser beams was fixed to 2.1ns, which was 6 times of 250ps(period of 2856MHz accelerating RF). The two laser beams were injected in the laser photocathode RF gun at an incident angle about 2^o by a prism which was placed in vacuum down stream of the gun.

Booster Linear Accelerator (Linac)

The generated double-decker electron beams were accelerated by an S-band booster linear accelerator up to about 31MeV. To compress the bunch length into femtosecond, an energy-phase correlation in the bunch was carried out by adjusting RF phase. The peak RF inputs of the RF gun and the linac were 10MW respectively. The RF inputs were produced by one 35MW Klystron.

Magnetic Bunch Compressor

The electron bunch was compressed into femtosecond by a bunch compressor. The compressor constructed with two 45^o-bending magnets and two pair of quadrupole magnets. It makes the path length of electron bunches that depends on the beam energy. The electron bunches were compressed into femtosecond by rotating and to rotate the electron bunches in longitudinal phase space distribution.

Pulse Radiolysis

The compressed upper beam was used as the pump source, and injected into a sample cell. The lower beam was converted to Cherenkov light. The Cherenkov light was used as the probe light.

Figure 3 shows the Cherenkov light radiation and collection parts behind the beam port. The Cherenkov light was collected by a thick mirror and a lens, then guided into the sample through an optical delay. The optical delay was used to adjust the timing of Cherenkov light and used for the time scan in pulse radiolysis.

The Cherenkov light passed through the sample was measured by a photomultiplier to calculate the absorbance of the sample.

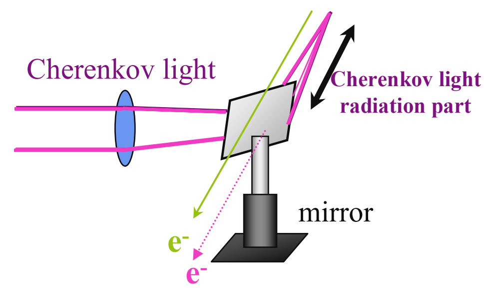

Figure 3: Cherenkov light radiation system.

EXPERIMENTAL RESULT

Figure 4 shows the beam profiles measured by a CCD camera at the exits of the RF gun, the linac and the pulse compressor. The beam profile at the exit of the compressor was measured in air. The beam profiles show that the double electron beams with up and down positions away from the accelerator axis, which was called ”double-decker electron beams”, were successfully

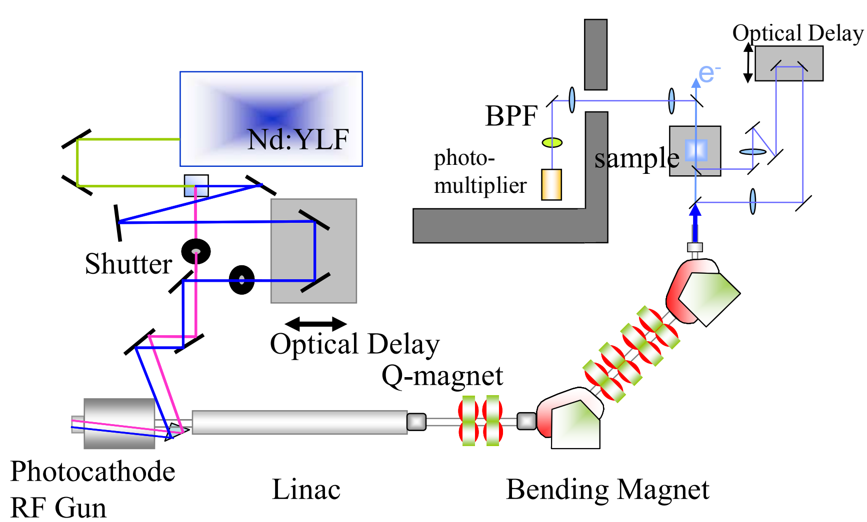

Figure 2: Overview of the experimental arrangement.

generated by the RF gun and accelerated by the linac. The beam size was 0.6mm in diameter and the distance of two electron bunches was 1.1mm at the exit of the RF gun.

Figure 5 shows the energy and energy spread of the beams. The measurement conditions were as follows: the RF gun phase was 30°, the solenoid magnet field was 2.71kG, the bunch charge was 2nC for both beams. The maximum beam energy was 30.9MeV and the minimum relative energy spread was 0.12% for the upper beam and 0.19% for the lower beam at the linac phase of 258°.

Figure 6 shows the time profile of the beams. The red plots show the time profile of beams when both beams were generated, while the blue plots show the case when only upper beam was generated. These profiles clarify the effect of the lower beam by closing one of the two laser beams. The time interval of the two beams was 2.1ns.

Figure 7 shows the normalized transverse emittance. The linac phase was fixed 258°and the RF gun phase was 30°.

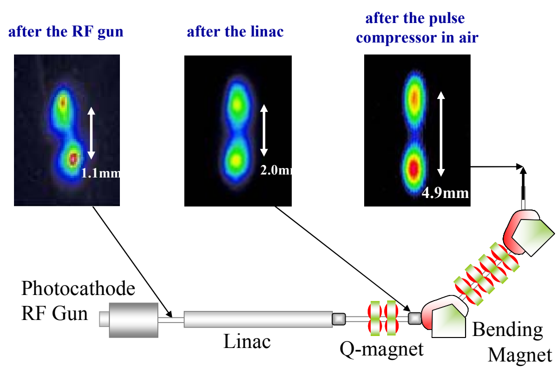

Figure 4: Beam profiles at the exits of the RF gun, the linac and the pulse compressor.

The red plots shows the normalized transverse emittance of the lower beam and the blue data shows that of the upper beam. The minimum normalized transverse emittance was 3.3mm-mrad for upper beam and 6.4mm-mrad for lower beam. The differences on the relative energy spread and the transverse emittance were caused by the different accelerating RF phase for both beams during the measurement.

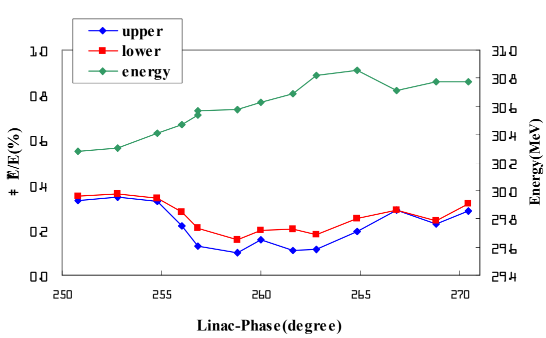

Figure 5: Energy and energy spread versus on the linac RF phase.

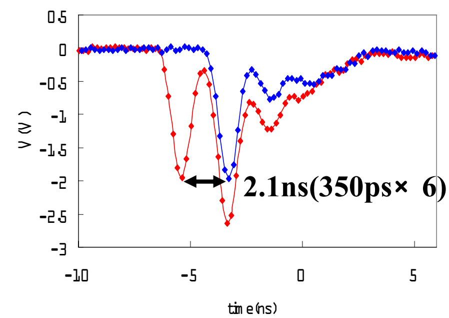

Figure 6: Time profiles of the beams.
Red: Both the beams.
Blue: Upper beam only.

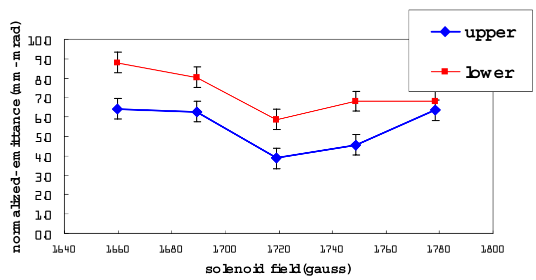

Figure 7: Dependence of normalized-emittance on the solenoid field.

SUMMARY

A double-decker electron beam accelerator was constructed for studying the ultra-fast reactions in spur. The double-decker electron beams were successfully generated by injecting two laser beams into the photocathode RF gun .The double-decker electron beams were successfully accelerated by the linac, and compressed into femtosecond by the magnetic bunch conmpressor. Beam profiles at the exits of the RF gun, the linac and the pulse compressor were measured. The beam energy, the energy spread and the normalized transverse emittance were measured for the both beams.

REFERENCES

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