GENERATION OF ULTRA SHORT ELECTRON PULSE AT ISIR L-BAND LINAC FOR SUBPICOSECOND PULSE RADIOLYSIS

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Abstract

A pulse radiolysis system by using a femtosecond laser synchronized with an electron linac was developed at Osaka University. The time resolution is several ten picoseconds. The pulse width of electron beams and the time jitter of the system mainly decide the time resolution of the whole system. This system has a potential to detect ultrafast phenomena in the femtosecond region. For the improvement of the time resolution of the laser synchronized pulse radiolysis system, we attempted to generate a shorter pulse by installing a magnetic pulse compressor to the L-band linac of Osaka University. Furthermore, in order to avoid effects of synchronizing jitter between electron pulse and laser pulse, a jitter compensation system was designed. In the preliminary experiment, the time resolution of less than 5 ps was achieved, which is the highest resolution in the world.

1 INTRODUCTION

A pulse radiolysis is one of the most powerful methods to study the very fast radiation-induced reactions. To detect so fast reaction, the so-called stroboscopic technique is used in the picosecond pulse radiolysis. The short-lived intermediates produced by very short radiation such as electron beams are detected by measuring the optical absorption of very short analyzing light such as Cherenkov radiation. The new picosecond pulse radiolysis system, in which the femtosecond laser is used instead of the Cherenkov radiation, was proposed at FST'95[1]. The merits of the laser system are as follows:

1) Obtaining the optical absorption in the wide wavelength region from 250 nm to 2 μm,
2) Easy to improve into femtosecond pulse radiolysis.

The most difficult point of the system is the synchronization of both the electron pulse and the laser pulse. The synchronization was succeeded at our laboratory of Osaka university first in the world in 1995, reported in FST'96[2]. In this system, the timing is controlled by radio frequency (RF) system. The time profile of the optical absorption can be obtained by changing the phase of the RF. The detectable wavelength is from ultraviolet to infrared by using SHG, THG, and OPO techniques etc.

The investigation on ultrafast phenomena in the picosecond regime have been started. The time-dependent behaviors of short-lived species in materials have been obtained. The subjects are:

1) Primary processes of radiation chemistry in polyethylene and its model compounds,
2) Observation of short-lived species of σ-conjugated polymer,
3) Study of radiation-induced reactions in materials for electron beam and X-ray lithography.

Our pulse radiolysis system by using a femtosecond laser synchronized with electron linac has a potential to detect ultrafast phenomena in the femtosecond region. The present time resolution is several ten picoseconds. The pulse width of analyzing light is 100 fs. However, the present pulse width of the electron beam is 20 ps. The pulse width of electron beams and the time jitter of the system mainly decide the time resolution of the whole system. If the present electron pulse width of 20 ps is reduced to femtosecond, and if the synchronization jitter is controlled precisely, the femtosecond pulse radiolysis will be realized. We attempted to construct a higher resolution system by installing a magnetic pulse

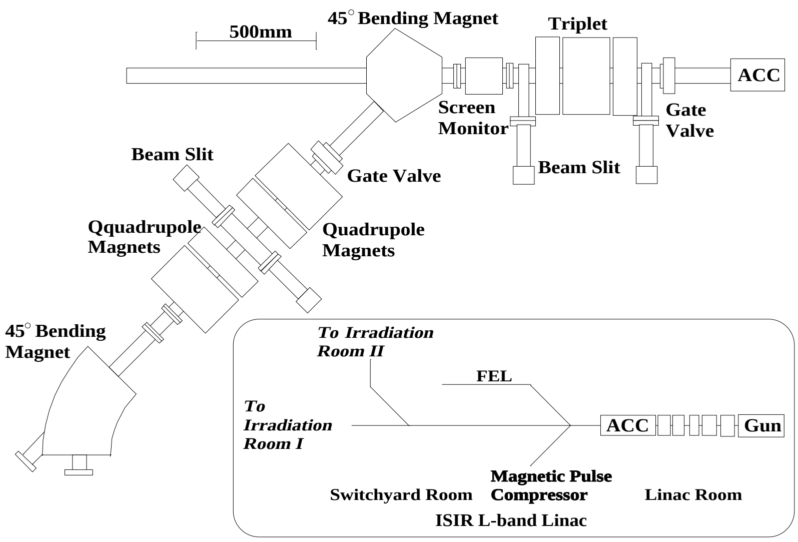

Fig. 1 Magnetic pulse compressor

compression system and a jitter compensation system.

2 EXPERIMENTAL SETUP

Figure 1 shows the ISIR L-band electron linac. The ISIR linac consists of an thermionic electron gun (YU-156, EIMAC), two 108 MHz (1/12 of the main accelerating microwave frequency of 1300 MHz) subharmonic buncher (SHB), a 216 MHz (1/6 of the main accelerating frequency) SHB, a 1300 MHz traveling wave type prebuncher, a 1300 MHz traveling wave type buncher, a traveling wave type accelerating tube and focusing system. The accelerating potential of the electron gun is provided by 90 kV DC.

A pulse compressor was installed at ISIR L-band linac as shown in Fig. 1. The achromatic pulse compressor consists of two 45° sector magnets, four quadrupole magnets and a beam slit in the horizontal direction. The longitudinal distribution of electron pulse is modulated for pulse compression by adjusting the RF phase in accelerating tube. The magnetic field in the pulse compressor effectuates a phase space transformation, translating the energy dispersion into a time correlated spread of trajectory lengths. Identically, the longitudinal distribution of fully accelerated relativistic beam should be modulated for magnetic pulse compression by adjusting the RF phase in an accelerating tube. However, ISIR L-band linac has only one accelerating tube. Therefore, in this experiment, acceleration and modulation were carried out by one accelerating tube, simultaneously.

Pulse width of a relativistic beam was evaluated by measuring Cherenkov radiation emitted by the relativistic electrons in air at the end of the beam line. The Cherenkov radiation was measured by using the picosecond streak camera which has the time resolution of 2 ps (Hamamatsu Photonics Co. Ltd.). An optical band pass filter, which is centered at 461.5 nm and has a half width of 10.7 nm, was used to avoid the pulse broadening due to optical dispersion in the convex lenses used in the measurement. All data were acquired by a single shot measurement to avoid effects of jitter during accumulation. Beam sizes were also measured by using phosphor screens (AF995R, Desmarquest Co. Ltd.) at the end of beam line.

3 RESULTS AND DISCUSSION

3.1 Numerical Simulation

The characteristics of compression are evaluated by a numerical electron tracking method. Figure 2 shows the effects of the beam slit at the center of pulse compressor. Simulation parameters used in the analysis are 235πmmmrad as 90 % normalized emittance, 0.2 % as the energy spread in the same phase, 70° as the accelerating phase of the traveling microwave in the accelerating tube and 10 MV/m as the peak electric field in the accelerating tube. It is found that the width of compressed pulse become shorter by installation of slit. When the width of slit is 40 mm, the width of compressed pulse becomes shorter with decreasing of the pulse width of initial beam before compression. However, in the case of 10 mm, the width of compressed pulse is independent of that of initial pulse.

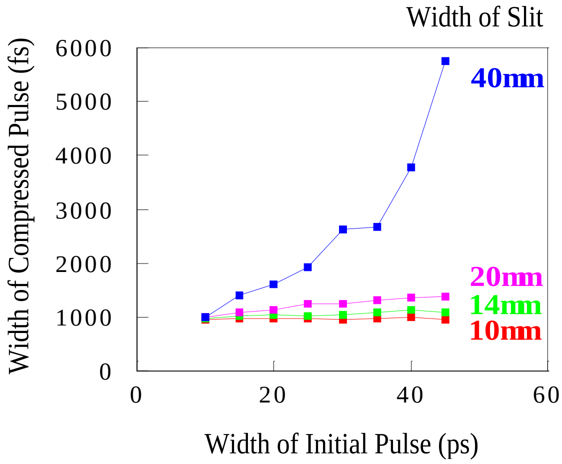

Fig. 2 Effects of beam slit at the center of the pulse compressor on efficiency of pulse compression

Figure 3 shows the relation between beam quality (transverse emittance and energy spread before modulation) and the width of compressed pulse. It is found that an efficiency of pulse compression depends on beam quality. High quality beam is necessary for the generation of ultra short pulse. One of the typical results of simulation is shown in Fig. 4. The beam parameters are 235 πmm mrad as 90 % normalized emittance, and 0.2% as the energy spread before the energy modulation. The width of slit is 10 mm.

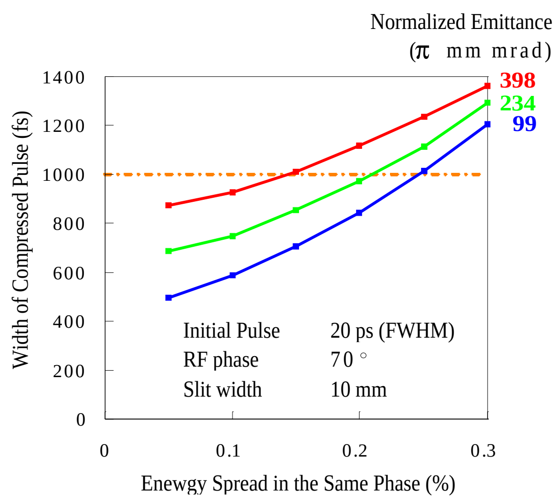

Fig.3 Relation between beam quality and width of compressed pulse

3.2 Magnetic Pulse Compression Experiment

The RF phase in the accelerating tube was tuned so as to accelerate electrons in the early phase of the pulse more than those in the later phase of the pulse. The peak electric field in the accelerating tube was adjusted to 10 MV/m. The magnetic fields of pulse compressor were adjusted so as to make the shortest pulse while monitoring its width by using the streak camera. The measured pulse shape of the shortest compressed pulse riding on the phase of 70° is shown in Fig. 5. The pulse width was 2.4 ps and the horizontal and vertical beam sizes (full width) of the compressed pulse were 5.0 mm and 6.0 mm, respectively. The charge was 2.0 nC/pulse. The measured pulse width of 2.4 ps is nearly equal to the time resolution of the streak camera. On the other hand, the calculated pulse width is subpicosecond. To make sure of this point, the spectra of coherent transition radiation generated by the compressed pulses were measured. At the wave length of 100 μm, a strong coherent radiation was observed. Therefore, we consider that the pulse width was subpicosecond.

3.3 Pulse Radiolysis

Figure 6 shows the synchronizing jitter compensation system for pulse radiolysis. The timing of the electron beam (Cherenkov light) and the laser pulse is measured by the streak camera. The laser pulse for the measurement of the timing is separated from the analyzing light by the half mirror. The precious time interval can be obtained by the analysis of the streak.

We carried out the preliminary experiment using <5 ps compressed electron pulse with the charge of 10 nC and femtosecond laser with the wavelength of 780nm. The time-dependent behavior of solvated electrons in neat water was measured. The time resolution was less than 5ps.

4 CONCLUSION

27 MeV electron pulses with the pulse width of 30 ps were compressed by the magnetic pulse compression system at ISIR of Osaka university. Subpicosecond single pulses were generated with the charge of 2.0 nC. In the preliminary experiment of pulse radiolysis, the time resolution of less than 5ps was achieved by using the compressed electron pulse with the pulse width of less than 5 ps and the synchronizing jitter compensation system. Now, the subpicosecond pulse radiolysis system using the subpicosecond pulse is under construction.

References

[1] Y. Yoshida et al., Proc. Femtosecond Technol. '95, (1995) 63.

[2] S. Tagawa et al., Proc. Femtosecond Technol.'96, (1996) 31.

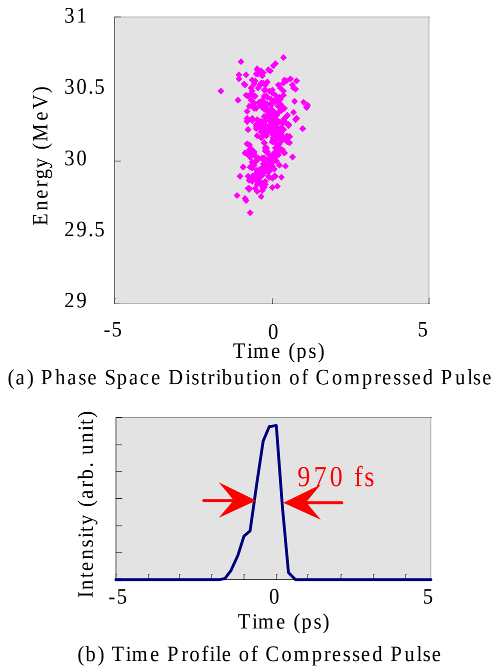

Fig. 4 Calculated longitudinal phase space distribution of compressed pulse

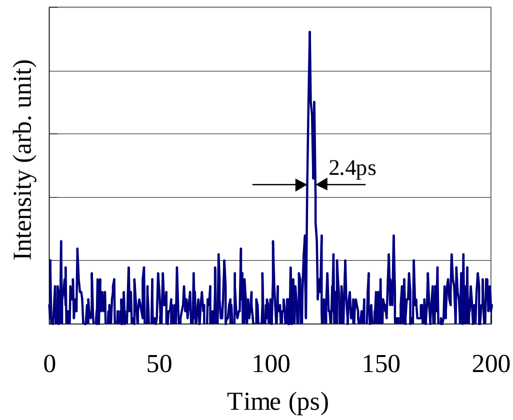

Fig. 5 Measured pulse shape of compressed electron pulse.

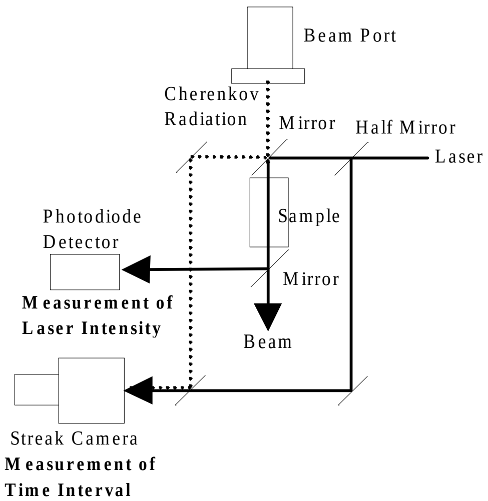

Fig. 6 Jitter compensation system for pulse radiolysis.