Generation of ultrashort electron pulse for laser synchronized picosecond pulse radiolysis system

Takahiro KOZAWA, Katsunori HORI, Yasuhiro MIZUTANI, Tamotsu YAMAMOTO, Shouji SUEMINE*, Yoichi YOSHIDA, Seiichi TAGAWA

The Institute of Industrial and Scientific Research, Osaka University, 8-1 Mihogaoka, Ibaraki, Osaka 567, Japan
**Unicom System, 6-24-28 Misaki, Suminoe-ku, Osaka 559, Japan*

Abstract

A pulse radiolysis system by using a femtosecond laser synchronized with electron linac was developed at Osaka University. This system has a potential to detect ultrafast phenomena in the femtosecond region. The pulse width of analyzing light is 100 fs. However, the present pulse width of the electron beam (irradiation source) 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. We attempted to generate a shorter pulse by installing a magnetic pulse compressor to the L-band linac of Osaka University. The pulse width of electron beams was measured by a picosecond streak camera with a time resolution of 2 ps. 27 MeV electron pulses with the pulse width of 30 ps have been compressed to 2.4 ps, which is equal to the time resolution of the streak camera, by the magnetic pulse compression system.

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

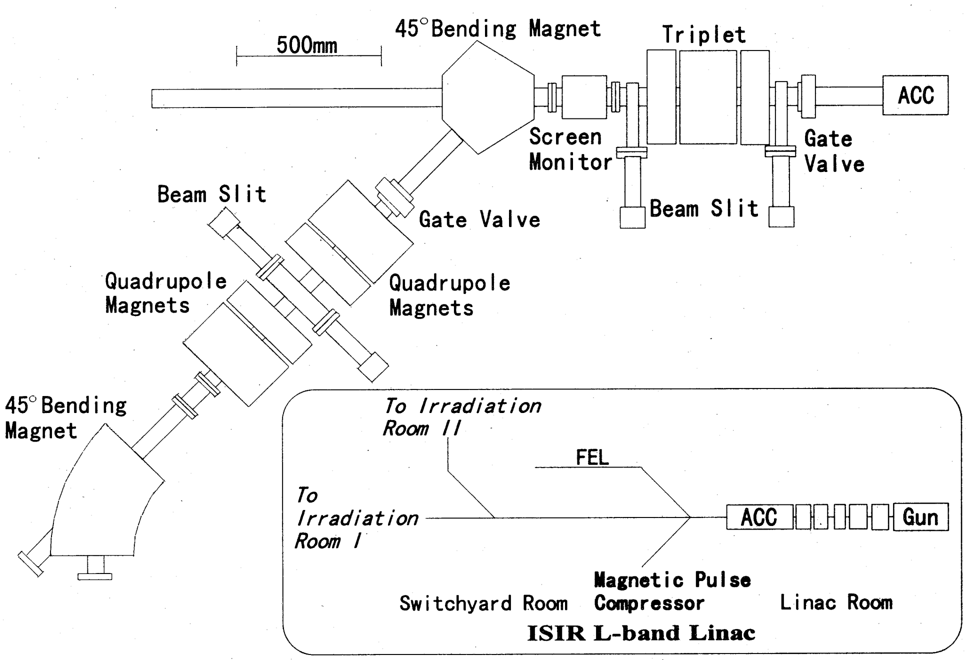


Fig. 1 Magnetic pulse compressor

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 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. The plan to make a shorter electron pulse has been started. A magnetic pulse compressor was installed to the L-band linear accelerator of the Institute of Industrial and Scientific Research, Osaka University (ISIR L-band linac). 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. We attempted to make a ultrashort pulse by magnetic pulse compression for improvement of time resolution of ISIR laser synchronized picosecond pulse radiolysis 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. 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 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

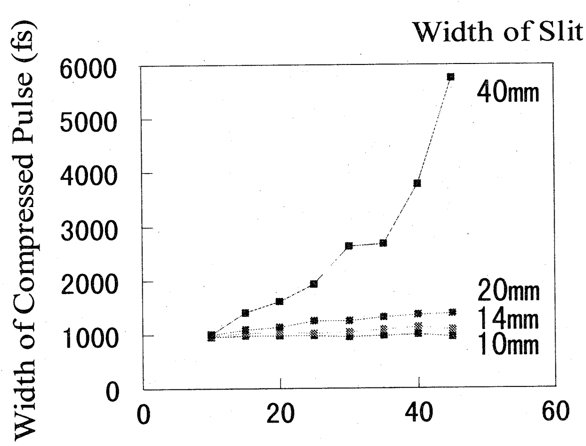


Fig. 2 Effects of beam slit at the center of the pulse compressor on efficiency of pulse compression

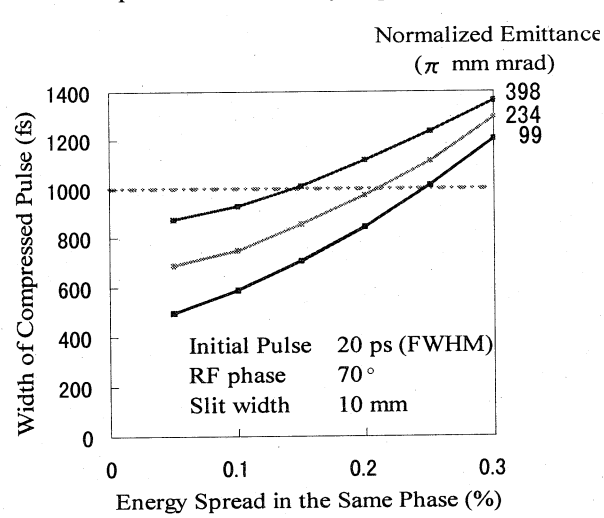


Fig.3 Relation between beam quality and width of compressed pulse

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.

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. Figure 4 shows the relation between the accelerating phase and the width of compressed pulse. It is necessary that the accelerating phase is less than 70° for the energy modulation. One of the typical results of simulation is shown in Fig. 5. 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.

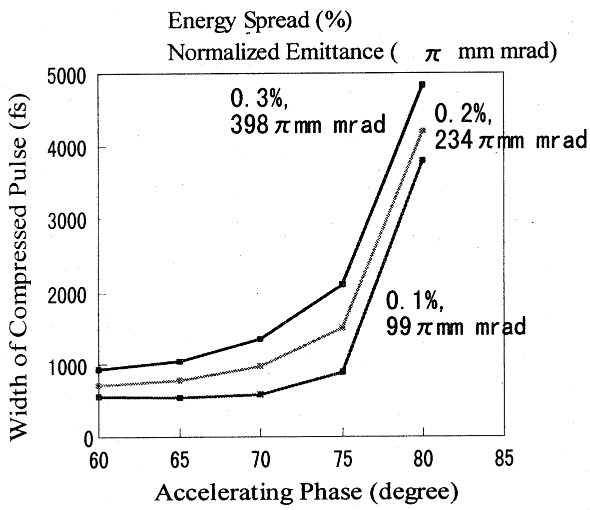


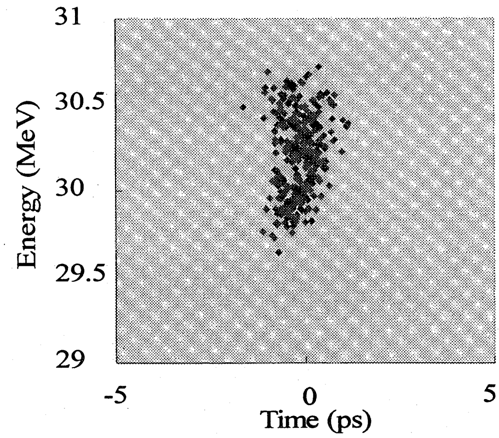
Fig. 4 Relation between the accelerating phase and the width of compressed pulse

3.2. Magnetic pulse compression experiment

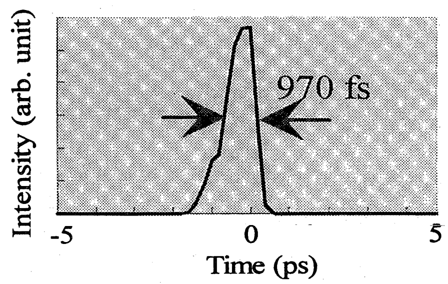
The RF phase in the accelerating tube was tuned so as to accelerate electrons in the early phase of the pulse more than those in the later phase of the pulse. The peak electric field in the accelerating tube was adjusted to 10 MV/m. The magnetic fields of pulse compressor were adjusted so as to make 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. 6. 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.

4. Summary

27 MeV electron pulses with the pulse width of 30 ps were compressed by the magnetic pulse compression system at ISIR of Osaka university. 2.4 ps single pulse was generated with the charge of 2.0 nC. The length of the pulse has been measured by a picosecond streak camera with a time resolution of 2 ps. The measured pulse width is equal



(a) Phase Space Distribution of Compressed Pulse



(b) Time Profile of Compressed Pulse

Fig. 5 Calculated longitudinal phase space distribution of compressed pulse

to the time resolution of the streak camera. Now, the picosecond pulse radiolysis system using the compressed pulses is under construction. This system will achieve the highest time resolution in the world. Furthermore, we attempt to make a shorter pulse (femtosecond electron pulse) by improvement of beam quality and to construct a femtosecond pulse radiolysis system.

References

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

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

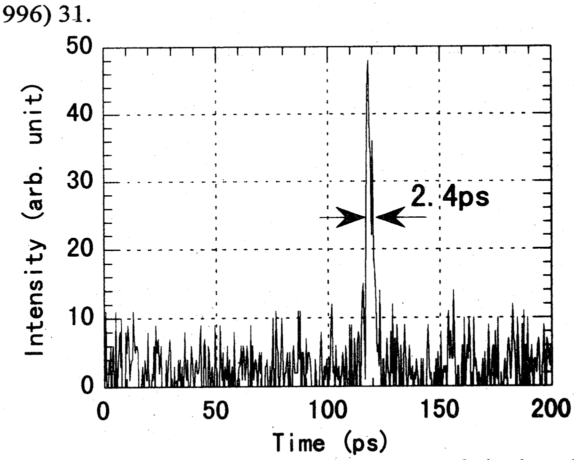


Fig. 6 Measured pulse shape of compressed single pulse