DESIGN AND CONSTRUCTION OF TWIN LINAC PULSE RADIOLYSIS SYSTEM

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ABSTRACT

The pulse radiolysis system which has a very high time resolution has been developed by using two parallel linacs. Each linac can accelerate single bunch beam (picosecond single beam) with a width of shorter than 10 picoseconds (ps). One linac of the two is used as an irradiation source, and the other is used as a Cerenkov light source. A portion of Cerenkov light pulse is absorbed by the transient species produced in a sample which is irradiated by a beam. Cerenkov light pulses which are used as a probe of an absorbing product can be delayed step by step and the time profile of the absorbing product can be obtained. The absorption signals of several samples have been obtained with a time resolution of 20 ps.

INTRODUCTION

The bunched beam of a linac is one of the good pulsed irradiation sources for pulse radiolysis system with a high time resolution[1], because the pulse width of the bunched beam is very short and the intensity of the beam is comparatively high. Especially the single bunch beams, that are also called picosecond single beam, are the excellent irradiation source for pulse radiolysis systems with a time resolution of better than 100 ps.[2,3,4] The purpose of the twin linac system is to obtain the 10 ps time resolution which has not yet achieved by any other systems. The twin linac pulse radiolysis system is a kind of Stroboscopic Pulse Radiolysis Systems developed by J. Hunt and his cowarkers.[1] The principle of the twin linac pulse radiolysis is briefly descibed using Fig. 1.

The transient species which absorb the light are produced in an irradiated sample and decay by reactions. The purpose of the system is to obtain the time profile of the concentration of the transient species with a very high time resolution. The irradiation source and the light source as a probe are necessary. One linac of the two is used as the irradiation sources and the Cerenkov light pulses produced by the other linac are used as a probe. The measuring procedure is as follows. The two linacs are operated repeatedly. Initially the light pulses pass through the sample cell before the beams irradiate the sample. The Cerenkov light pulses are delayed step by stpe. The signals are repeated by N times -typically 64 times- at every step to obtain good signal to noise (S/N) ratio. A portion of the Cerenkov light pulse is absorbed in propotion to the concentration of the transient species. The delay time of the Cerenkov light pulses corresponds to the time axis of an absorption signal. So absorption signals can be obtained by using two linacs.

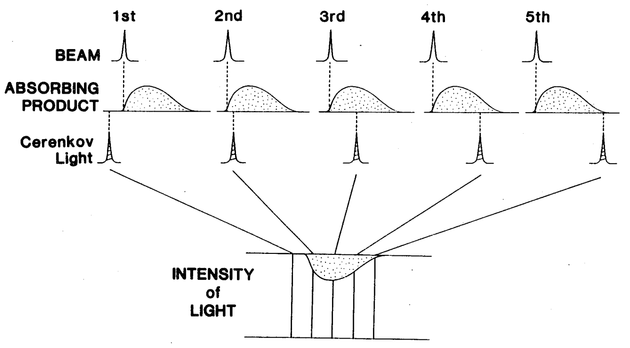

Fig. 1. The principle of stroboscopic pulse radiolysis (Twin Linac Pulse Radiolysis)

LINAC SYSTEM

The block diagram of the twin linac pulse radiolysis system is shown in Fig. 2. Each linac can accelerate picosecond single electron beams with a width of shorter than 10 ps. Two linacs are installed at a distance of 750 mm. One linac (ACC-I) of the two has a beam energy of 15 MeV and is used as an irradiation source. The other one (ACC-II) has a beam energy of 20 MeV and is used as a Cerenkov light source. The beam energy of 20 MeV is lower than the threshold energy for Cerenkov light generation in the air. So the Cerenkov radiator which contain xenon gas at 1 atm. is attached at the beam window of the linac. The beam with a energy of 15 MeV has enough penetration as the irradiation source. The main parameters of these two linacs are shown in Table 1.

	Irradiation source	Light source
Beam Energy	15 MeV	20 MeV
Output Charge	1.5 nC/pulse	0.1 nC/pulse
Rep. rate (max)	200 Hz	200 Hz

Table 1. Parameter of two linacs

TIME INTERVAL BETWEEN TWO BEAMS

The time interval between two beams which are accelerated by the ACC-I and by the ACC-II respectively can be changed by delaying the beam of the ACC-II. The beam of the ACC-II can be delayed by three phase shifters which are connected by a dotted line in Fig. 2. These three phase shifters are drived simultaneously and are

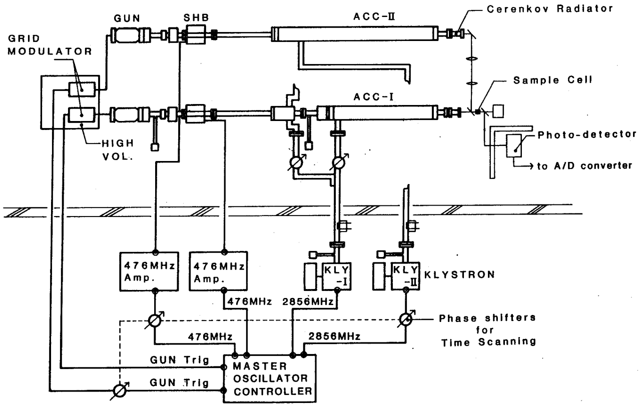

Fig. 2. The block diagram of Twin Linac Pulse Radiolysis System

used to delay the grid triggers for the electron gun, the microwave for the subharmonic prebunching cavity (SHB) and the microwave for the accelerating structure in the ACC-II system. The maximum delay time is 2 ns, although it is easy to expand the longer time limitation. The accuracy of time axis is ± 0.7 ps. The time axis has 1024 channels each of which corresponds to 2 ps.

MICROWAVE SYSTEM

The block diagram of microwave system for the twin linac pulse radiolysis system is shown in Fig. 3. The frequency of the master oscillator is 476 MHz. The microwave for the klystrons is obtained by multiplying the master microwave by 6. The microwave with a frequency of 476 MHz is amplified by solid state amplifiers and is divided into two aprts. Each of them is amplified by amplifiers up to 2 kW and is fed to the SHB. The microwave with a frequency of 2856 MHz is also amplified by a solid state amplifiers and is divided into two parts. Each of them is amplified by the amplifiers composed of plannar triodes up to 100 W and is fed to the klystron. The outputs of the klystron I and of the klystron II are fed to the accelerator I and to the accelerator II respectively.

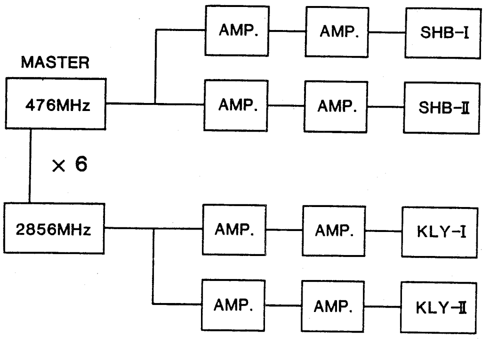

Fig. 3. The block diagram of microwave system

ELECTRON GUN SYSTEM

For the twin linac pulse radiolysis system, two electron guns are used but only one high voltage power supply for them is used and is enough. To produce a picosecond single beam, the very short electron beam is necessary. For example, to obtain the output charge of 1.5 nC, the input charge of about 3 nC with a pulse width of 0.8 ns is necessary. The beam energy of the gun emission is considered to be supplied by the stored energy in the gun structure. The energy of beam which is extracted from the gun is about 2.7×10^{-4} J, and the stored energy in the gun structure is estimated to be about 4×10^{-2} J.

The grid modulators for the guns are composed of avalanche transistors and installed at the high voltage deck of the high voltage power supply. The triggers for the grid modulators are applied through glass fibers to insulate the high voltage of 90 kV.

TIME JITTER

The time jitter between two beams which are accelerated by two parallel linacs is one of the most important problems in the twin linac pulse radiolysis system. The bunching procedure in an accelerating structure should be considered. At the bunching section, the injected electrons oscillate and are gradually bunched at the stable phase. When the buncher section of a linac is properly designed, a comparatively wide phase acceptance can be obtained. At present, it is difficult to emit the electron beam from the electron gun with a time jitter smaller than 20 ps. But the time jitter of injected beam is reduced through bunching procedure. Electrons on the acceptance angle are bunched in the narrow phase. Suppose that the two linacs which have the same bunching section are prepared. The time jitter between two beams accelerated by the parallel linacs corresponds to the phase jitter between two high power microwave sources which are for two accelerating structures. So the timing of output beams does not depend on the timing of injector but on the phase of microwave. The phase modulation of a klystron is mainly due to the fluctuation of anode voltage for the klystron. The time jitter between two beams due to the fluctuation of anode voltage of the klystron which is used in the system can be calculated and is about 3 ps/0.5 %. The very stable high power pulser for the klystron is needed to obtain high time resolution.

BEAM SWITCHING SYSTEM

To calculate the absorption of an analyzing light, the background light produced in a sample by an irradiation source should be subtracted. So the three different kinds of operational modes are necessary. These are as follows.

(A) The only analyzing light is produced. The accelerator for the Cerenkov light is operated.

(B) Both the electron beam and the Cerenkov light are produced. Both the accelerator for the electron beam and the accelerator for the Cerenkov light are operated.

(C) The only electron beam is produced. The accelerator for the electron beam is operated.

The fraction of absorption can be calculated by using these three operational modes. These three operational modes are controlled by the grid triggers of the grid modulators for electron guns. The block diagram of the beam switching system is shown in Fig. 4. The output triggers of the synchronization circuit are gated by a logic IC. The gate for the ACC-I is opened at the modes of (B) and (C). The gate for the ACC-II is opened at the modes of (A) and (B). The system is operated in continuous sequence ABCABCABC.....

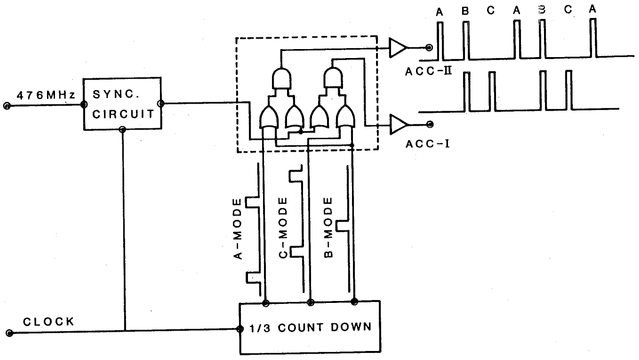

Fig. 4. The sequence of the switching system. The output triggers of the synchronization circuit are switched by an emitter coupled logic IC. The gate for the ACC-I is opened at the modes of (B) and (C). The gate for the ACC-II is opened at the modes of (A) and (B).

OPERATION OF LINAC SYSTEM

The linac system was operated and the performance of that was measured. Each of two linacs was confirmed to produce picosecond single beams by a streak camera. The output charge of each linac is shown in Table 1.

The sequence of beam switching was also confirmed to be the same as described in the section of beam switching.

The delay of the beams of the ACC-II was also confirmed by an oscilloscope. The oscilloscope was triggered by the beam of the ACC-I and the beams of ACC-II were monitored by the oscilloscope. The beams were delaying step by step and were shown in Fig. 5.

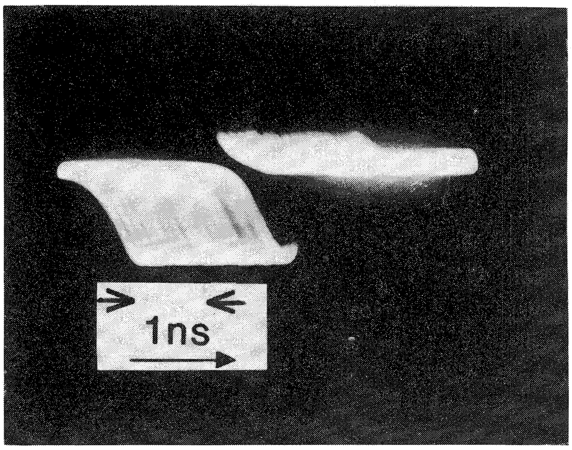

Fig. 5. An oscilloscope trace of the beams of ACC-II. The beams of the ACC-I were used as triggers for the oscilloscope. The shutter of a camera was continuously opened during the beams of the ACC-II were delaying.

DATA ACQUISITION

The intensity of the light is detected by a photomultiplier. As described in the section of beam switching system, when the mode (A) is operated, the intensity of analyzing light which is not absorbed is detected. When the mode (B) is operated, the analyzing light which contain absorption signal with the background light such as emission from the sample is detected. When the mode (C) is operated, only the background light is detected. The absorption signal can be obtained by addition and subtraction of these three signals, ie., absorption signal = A - (B - C). The intensity of light is converted to digital form by an A/D converter. A minicomputer is used to calculate and to store the absorption signals. To obtain good S/N, the set of (A), (B) and (C) is repeated by N times. And then the stepping motors for phase shifters are driven. Then the next data acquisition starts.

RESULT

The system has been applied to absorption spectroscopy of several samples. The time resolution of the system was checked by absorption signal of hydrated electron in water at 700 nm. The rise time of the signal was about 25 ps. The time resolution of the system was mainly due to the desynchronization of the electron pulses with the slower analyzing light pulses as they pass through the 2 cm detection cell. An appreciable improvement in time resolution would be obtained by using the thin detection cell. The time resolution of better than 10 ps is expected by using 5 mm detection cell.

As examples of signals obtained by using the twin linac pulse radiolysis system, the absorption signals of liquid carbon tetrachloride (CCl_4) at 330 nm and at 480 nm are shown on the left and on the right respectively in Fig. 6. The following important results have been obtained by using the twin linac pulse radiolysis system.

1. The absorption around 330 nm is composed of at least two parts; very short-lived and long-lived ones.
2. The formation processes of the absorption around 480 nm is composed of at least two parts; the faster (within the limitation of time resolution of the system) and the slower ones.

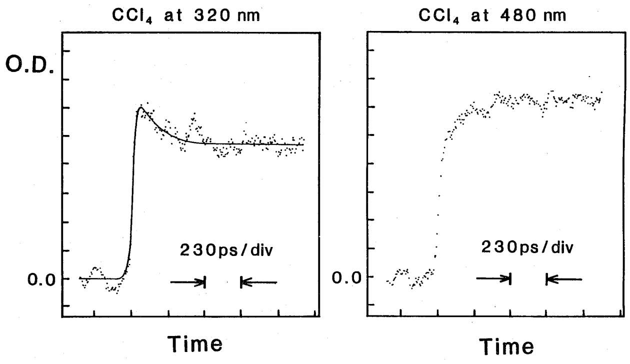

Fig. 6. The absorption signals of liquid carbon tetrachloride (CCl_4) at 330 nm and at 480 nm are shown on the left and on the right respectively. These signals are obtained by using the twin linac pulse radiolysis system.

ACKNOWLEDGEMENT

The authers wish to thank Prof. S. Tagawa, Dr. Y. Katsumura and Dr. M. Washio for their helpful advice.

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