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Current Status Report of Femtosecond Triplet Electron Linac at Nucl. Eng. Res. Lab., University of Tokyo

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Abstract

240fs, 17MeV electron beam generation and 3.5fs (rms) resloved synchronization with 100fs Ti:Sapphire laser were achieved at the S-band twin linac of Nuclear Engineering Research Laboratory, University of Tokyo, in 1998. The Femtosecond Quantum Phenomena Research Facility has been constructed in 1999. The facility consists of the femtosecond linac-laser synchronization system, the 20TW 50fs laser system and the analyzing system(X-ray Diffractometory, X-ray CCD camera, XPS, FTIR). The first enables 320fs(rms) linac-laser synchronization, which is dedicated to subpico-through nano-second time-resolved radiation chemistry work for mainly supercritical water chemistry. Especially, numerical and experimental analysis on 10fs 10MeV electron beam using the 12TW 50fs laser and laser plasma wake wave breaking are under way, which is called a laser plasma linac. Thus, a new femtosecond triplet linac system is formed.

1 Introduction

Generation, measurement and ps-resolved synchronization of subpicosecond electron and laser beams have been fully experienced at the S-band twin linacs system of Nuclear Engineering Research Laboratory, University of Tokyo[1,2,3]. We are going to proceed forward to the femtosecond quantum beam science with a newly installed Femtosecond Ultrafast Quantum Phenomena Research Laboratory. 320fs(rms) resolved synchronization of 240fs(FWHM) electron and 100fs(FWHM) Ti:Sapphire laser is going to be applied to radiation chemistry analysis of supercritical water. Ps-resolved X-ray diffraction to visualize atomic motions is also under way. Numerical analysis of 10fs 25MeV electron beam generation via a laser plasma linac has started. Its experiment using the 12TW 50fs laser is to be done in 1999. The S-band twin linacs and the laser plasma linac form a new triplet femtosecond linac system. Specification of the new facility and updated results are presented.

2 Femtosecond Ultrafast Quantum Phenomena Research Faculty

The facility has been installed at the laboratory. Here the upgraded femtosecond S-band twin linac with 100fs stable Kerr-lens-mode-locked Ti : Sapphire laser, the 12 TW 50 fs laser, X-ray diffraction analysis devices, X-ray CCD camera system, X-ray electron spectroscopy (XPS) device and the Fourier transform infra-red (FTIR) spectroscopy device have been installed as shown in Fig.4. Hundreds fs time-resolved pulseradiolysis for radiation chemistry is available using the first, while several basic researches of tens fs beams (electron, ion, neutron) are performed via laser plasma linac using the 12 TW 50 fs laser. After we have succeeded in the beam generation experimentally, we are to proceed to a variety of tens fs time-resolved pump-and-probe analyses.

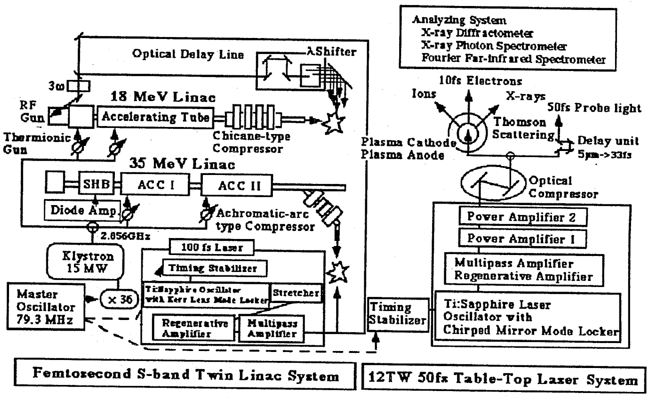


Fig.1 Femtosecond ultrafast quantum phenomena research facility.

3 Electron Bunch Diagnosis

We have performed the comparison of measurement of subpico- and picosecond electron pulses among the femtosecond streak camera, the Michelson interferometry and the polychromator measurement as shown in Fig.2[4]. We measured the transition radiation in the far-infrared region emitted by an electron bunch at the Al-foil put in the air after the 50 μm-thick Ti window at the end of the 35L linac. We used liquid-He-cooled Si bolometers as a detector for the far-infrared radiation. The major beam parameters are as follows: the energy was 34 MeV, the pulse length is from about 600 fs to 8.0 ps (FWHM) and the electron charge per bunch is controlled to be 10 to 100 pC avoiding the over-scale of the detectors.

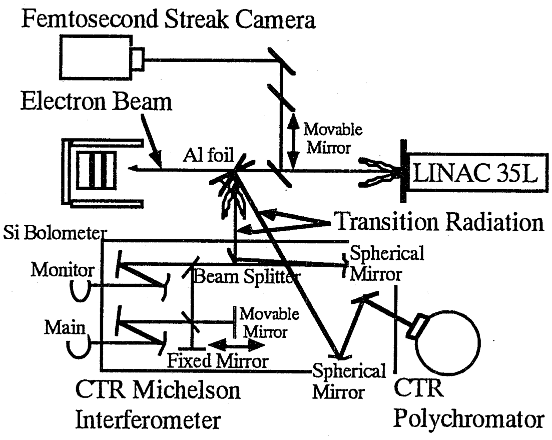


Fig.2 Diagnostic setup

The longitudinal distribution is evaluated based on the theory of coherent transition radiation. The longitudinal bunch form factors obtained by the two methods were rather limited because of the nonuniform transparency of the 100 μm-thick Mylar beam splitter in the Michelson interferometer and measurement region which depends on the grating pitch (1.0 mm) installed in the polychromator. Therefore we have to adopt theoretical extrapolation assuming the Gaussian or exponential distributions out of the range, referring to the pulse shape measured by femtosecond streak camera. The CTR spectrum calculated from the interferogram and by the polychromator are shown by the solid curves and the transparency of a 100 μm-thick Mylar-type beam splitter by dashed curve in Fig.3. From the figure, we decided to use the experimental data in the range of 9.5 to 18.0 cm^{-1} for the analysis in the interferometry, while the measurable range of the polychromator was already determined from 12.2 to 26.2 cm^{-1} discretely by the 1mm grating pitch.

Finally, we reconstructed the longitudinal bunch distributions after using Kramers-Kronig relation to derive the phase information. The result of the subpicosecond pulse measurement by the interferometry and that by the polychromator were 650 fs and 1.0 ps at FWHM as shown in Fig.4. Typical result by the streak camera is also shown in the same figure. Here we have got reasonable agreement and confirm the enough reliability of the diagnostics methods by the CTR measurement.

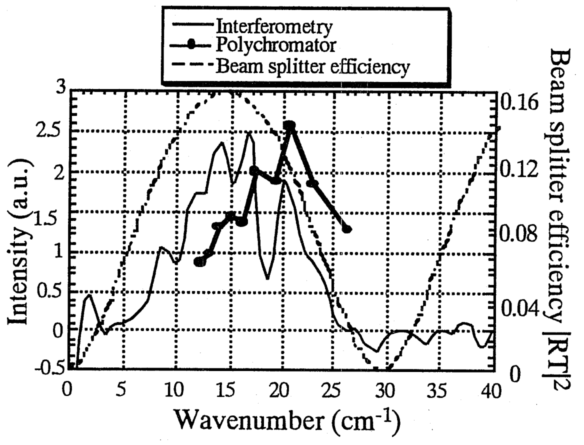
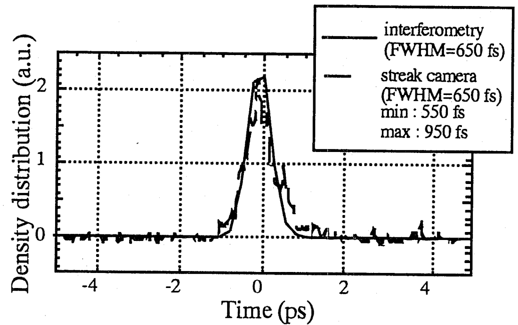
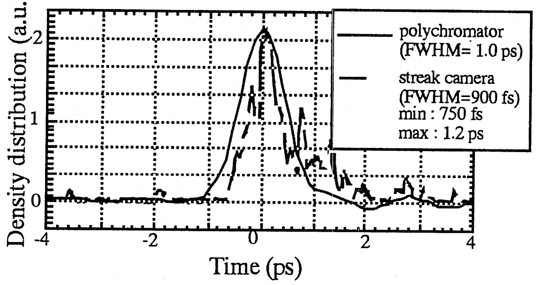


Fig.3 Spectrum of CTR



-Results by the interferometry-



-Results by the polychromator-

Fig.4 Bunch distributions by the three methods

We expect the CTR methods are promising for the shorter electron beam (< 200 fs) with better resolution because the spectrum shifts from the far-infrared region to the infrared region where the sensitivity of the detector becomes better. Especially, the polychromator can be expected to the most useful methodology because of the advantage of diagnostics by a single shot.

4 New Linac-laser Synchronization System

In order to achieve subpicosecond linac-laser synchronization, we have designed and constructed a new sustem introducing the most advanced technologies as shown in the left-hande side of Fig.1. The technologies are; Kerr-lens-mode-locked Ti:Sapphire laser with the 10th harmonics rf synchronizer, the compact laser amplifiers, the stable 15 MW klystron rf power supplier, the room-tempreture-controlled laser clean room and the vacuum laser transport line and so on. Timing jitters between the electron and laser pulses at the major sources are evaluated in Table.1. The electron beam jitter corresponds to the jitter of TOF of the electron bunch due to fluctuations of rf power and phase ,which are evaluated by the klytron performance data and PARMELA simulation. The total timing jitter between the electron and laser pulses is expected to be ~320 fs (rms) in the new experimental system.

	Previous System		New System
Thermionic Gun Linac	Trigger	Electric Sync. Circuit	
RF gun linac	Laser	YLF + Ti:Sapphire	one Ti:Sapphire
Klystron	Power Number	7 MW×2	15 MW×1
	Power Jitter	>1%	<0.5%(rms)
	Phase Jitter	>1°	0.2° (rms)
Electron Beam Jitter	a few ps(rms)		300fs(rms)
Laser Jitter	~3 ps(rms)		100fs
Total Jitter	> 3 ps(rms)		320fs

Table 1 Timing jitters in the previous and new systems.

5 Linac Based Time-resoved X-ray Diffraction

Linac Based Time-resoved X-ray Diffraction to visualize atomic motions was tried using the previous linac-laser synchronization system. 35MeV, 10ps (FWHM), 1nC electron single bunch was irradiated with the 100μm^t Cu wire to generate Cu $K\alpha_{1,2}$ X-rays(8.048, 8.028keV). Generation of 10ps Cu $K\alpha_{1,2}$ X-rays was confirmed by the numerical analysis using the EGS4 code. The 100fs 3TW Ti : Sapphire laser was used as a pump pulse to induce nonequilibrium thermal expansion. We used monocrystal semiconductors of Si(111), GaAs(111), Ge(111), ion crystals of NaCl(200), KCl(200) and monocrystal alkalihalides CaF_2(220), BaF_2(111). X-ray diffraction image is drawn on an X-ray imaging plate set in the noise-radiation shielding box. The number of photons of the X-ray per shot is estimated to be about 10^6. Thus, we need 10^4-10^5 times repetition for the pump-and-probe shot. Cu $K\alpha_{1,2}$ X-ray diffraction images from all specimens were successfully obtained[6]. The pump-and-probe analysis was carried out for a GaAs specimen. However, its surface suffered laser-irradiation damage before the X-ray diffraction image for deformed lattice was obtained. The damage may attribute physical ablation and photo-chemical reaction with air. Since 10^3 times more photons per shot are expected from fs TW laser induced plasma, we have shifted to its experiment to get an X-ray diffraction image by a single shot.

6. Laser Plasma Linac

When 12 TW 50 fs laser is focused down to about 10 μm in diameter into 1 mm ϕ gas jet in a vacuum chamber, laser plasma and electromagnetic wake wave are induced. If the laser vector potential proceeds the wake wave limit, the wake wave energy is transferred to the longitudinal energy of electrons in plasma. Thus, pre-acceleration and injection of an electron bunch onto the wake wave is achieved. Since the plasma length is rather short as less than 1 mm, a single relativistic electron bunch is generated before the phase slippage occurs. This is called as a laser plasma linac, where only a single 12TW 50fs laser is used and the wake wave breaking is sophisticatedly handled. PIC-2D simulations show that about 25 MeV, a few fs, tens pC electron bunch is available[7]. Improvements of the configuration is under way. The experiment is planned this December.

Reference

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