SUBPICOSECOND ELECTRON AND PHOTON BEAM RESEARCH

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Abstract

700 fs(FWHM) electron single pulse from the S-band (2.856 GHz) linear accelerator (linac) of the Nuclear Engineering Research Laboratory of University of Tokyo was generated in 1994. Femtosecond electron pulse measurement system also has been developed using the femtosecond streak camera and coherent far-infrared transition radiation interferometry. Then it was synchronized with 100 fs(FWHM) 3 TW laser pulse from a T^3 (Table-Top Terawatts) laser with a picosecond time resolution. The Synchronized laser and electron linac are used for laser wakefield acceleration, femtosecond X-ray generation via Thomson scattering and pulseradiolysis for radiation chemistry. Recenltly, the laser photocathode RF(radio frequency) electron gun was introduced to the linac and 440 fs elcetron pulse was produced. Futher we generated picosecond X-ray pulse by irradiating a Cu target by picosecond electron pulse and obtained Bragg diffraction from a NaCl ionic monocrystal using a high sensitivity X-ray imaging plate. Finally, we propose and discuss a new pump-and-probe analysis to observe dynamics of atoms by using the synchronized laser (pump) and X-ray (probe).

1 INTRODUCTION

Recently, there has been remarkable progresses in producing ultrashort pulses by lasers and particle beam accelerators. Now high-powered 100 femtosecond laser pulses are available by table-top lasers and a subpicosecond electron pulse by linear accele-rators[1,2,3,4]. Ultrashort synchronized pulses lead to an ultrafast time-resolved pump-and-probe analysis, which is capable of observing new ultrafast phenomena in quantum beam-material interaction. Thus, femtoseond qauntum beam generation&measurement based on the femtosecond electron linac and laser and their accurate synchronization is of much recent interest. In the Nuclear Eingineering Research Laboratory of University of Tokyo, the synchronization system has been developed and applied to several new experiments; laser wakefield acceleration, femtosecond X-rays generation via Thomson scattering and subpicosecond pulseradiolysis for radiation chemistry and new pump-and-probe time-resolved X-ray diffraction analysis. Furthermore, a new laser photocathode RF electron gun which can produce 440 fs electron beam with high qulality, namely low emittance, was introduced to the linac. This new system has great potential as to more precise synchronization since one femtosecond laser can supply both electron(pump) and laser(probe) beam. In this paper, the recent progresses, the synchronized electron linac and laser system, the diagnotics system and its application to investigate ultrafast radiation-induced phenomena are presented.

2 UPGRADED TWIN ELECTRON LINAC SYSTEM

The S-band twin electron linac system[1] has been upgraded with a new laser photocathode RF gun as shown in Fig.1.

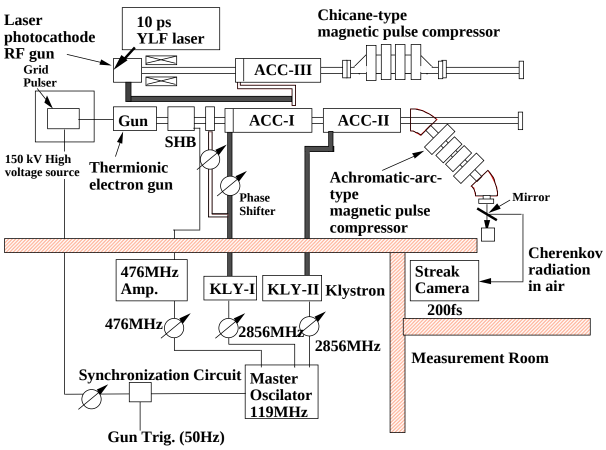

Figure:1 Upgraded twin electrom linac system.

The first linac (35L) has two accelerating tube and its maximum electron energy is 35 MeV. The second linac(18L) has one tube and its maximum electron energy is 18 MeV. Maximum charge per one pulse is 1 nC in both. Here we can compress 10 ps(FWHM) relativistic electron single pulse to femtoseond pulse by using the technique of the magnetic pulse compression. Energy modulation of electrons in a bunch is done by putting the bunch on the sloped phase of the traveling wave in an RF accelerating tube. This process corresponds to the chirping in the chirped pulse compression. Then the energy modulation is converted to the path length modulation in the magnet assembly so that the electrons in the later half of the pulse catch up with ones in the earlier half. Finally the compression of the pulse is achieved. There are two types of the magnet assembly which are achromatic-arc-type and chicane-type as shown in the figure. They correespond to the down- and upward chirpings, respectively. The achromatic-arc-type and

chicane-type magnet assemblies are used in the first and second linacs as shown in the figure, respectively. 700 fs electron single pulse was achieved in the first linac[1].
Recently, the new laser photocathode RF gun was installed in the second linac. Its updated behavior appears in ref.[5]. The diagnostics system for the femtosecond electron pulse consisting the femtosecond streak camera and coherent far-infrared transition radiation interferometry have had remarkable progress[6,7,8,9].

3 SYNCHRONIZATION SYSTEM

The T[3] laser consists of the Ti:Sapphire oscillator, the stretcher, the regenerative amplifier, the pulse selector, the multipass amplifier and the optical compressor. The schematic drawing of the synchronization system between the linac and laser is shown in Fig.2.

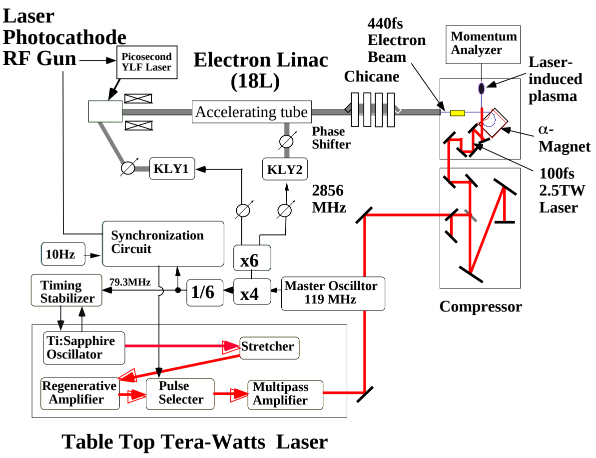

Figure:2 Synchronization system of femtosecond laser and electron linac.

Here we chose 119 MHz as the main RF source. Then we generate higher harmonics (476 MHz, 2.856 GHz, etc.) and subharmonic (79.3 MHz) by the frequency multipliers and dividers, respectively. The trigger pulses synchronized with a specified phase of 79.3 MHz is generated by the synchronization circuit at 10 Hz. The repetition rate of the laser oscillaotor is precisely fixed to 79.3 MHz by the timing stabilizer (or so-called mode locker). The RF synchronized trigger pulses run the electron gun of the linac and also select the laser pulse at 10 Hz. Further, the trigger pulses are used to run several diagnosis devices including the femtosecond streak camera. The selected laser pulse is transported to the optical compressor through a vacuum pipe and compressed. Finally, the pulse width (FWHM) , energy per pulse and peak power are 90fs, 300mJ and 3.3TW, respectively. Cherenkov radiation pulse emitted by the electron pulse in air and the laser pulse are introduced to the streak camera. The time interval between the electron and laser pulses is adjustable by several time-delay units in the synchronization system. The synchronization was confirmed and those pulse shapes were obtained by the femtosecond streak camera. We can measure them on-line by a single event. The measured streak image and pulse shape are shown in Fig.3. We evaluated the time-jitter of 3.7 picoseconds at the standard deviation between the two pulses.

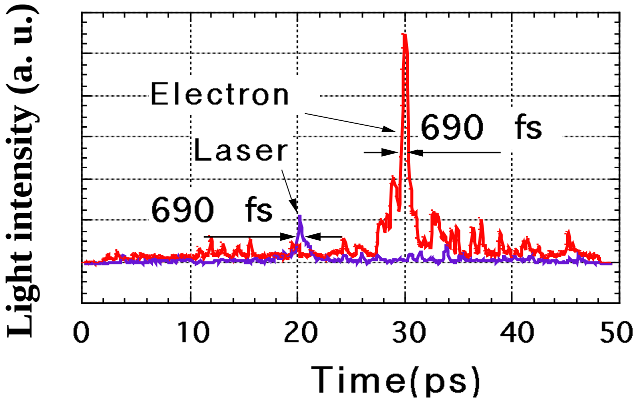

Figure:3 Synchronization of femtosecond electron and laser pulses.

This precise synchronization system has enabled us to contribute to the laser wakefield acceleration[10] and the Thomson scattering X-ray generation[11]. The experimental evidence of the 90 dgree scattering is shown in Fig.4. Generated X-ay signal measured by the scintillator is plotted as a function of the time delay from the laser to the electron beam.

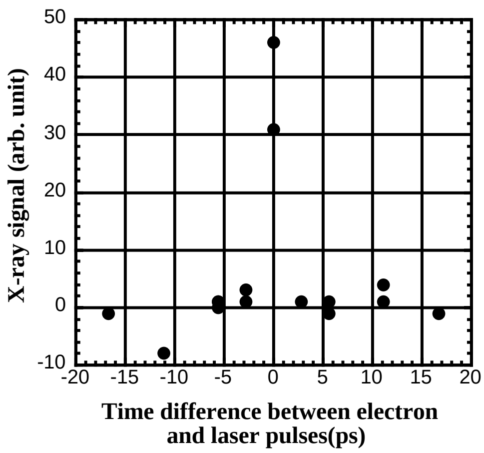

Figure:4 Thomson scattering X-ray signal.

4 NEW PUMP-AND-PROBE ANALYSIS

We are going to promote a new pump-and probe analysis based on femtosecond TW laser and more relativistic electron linac. Here we can choose pump- and probe-beams out of laser, electron, X-ray, coherent far-infrared radiation, neutron, ion etc. so that we can perform several types of pump-and-probe analysis. The pump-and-probe analysis using synchronized femtosecond quantum beams enables dynamic microscopic observation of ultrafast processes in radiation-incluced dynamics of electrons, atoms and molecules.

As the first stage, we plan to perform a new method of picosecond time-resolved X-ray diffraction to observe transient thermal expansion of laser-irradiated monocrystal. Here we use the synchronized femtosecond TW laser and picosecond X-ray generated by irradiating a Cu target by picosecond relativistic electron beam from the linac.

As the preliminaryt step, we generated the picosecond X-ray via Bremsstrahlung and Compton processes from a Cu target irradiated by the 10 ps electron pulse. The samples of a monocrystal are NaCl, Si, GaAs etc. The static view of the lattice structure of the NaCl monocrystal has been obtained so far by using the measurement system as shown in Fig.5[12]. Since we did not use any X-ray monochromator there, both the Bragg diffraction spot due to the cubic structure and the noise spot due to the X-rays with other wavelengths are obtained as shown at the bottom in the figure.

After we succeed in the above analysis, we will proceed to upgraded analysis to investigate transient phase-transition of dielectric materials and to the analysis to visualize lattice vibratioon with a femtosecond time resolution using femtosecond laser and X-ray pulses. Simultaneously, the subpicosecond pulseradiolysis study to investigate ultrashort radiation chemistrical processes plan to be carried out at the 18L linac with the laser photocathode RF gun in near future.

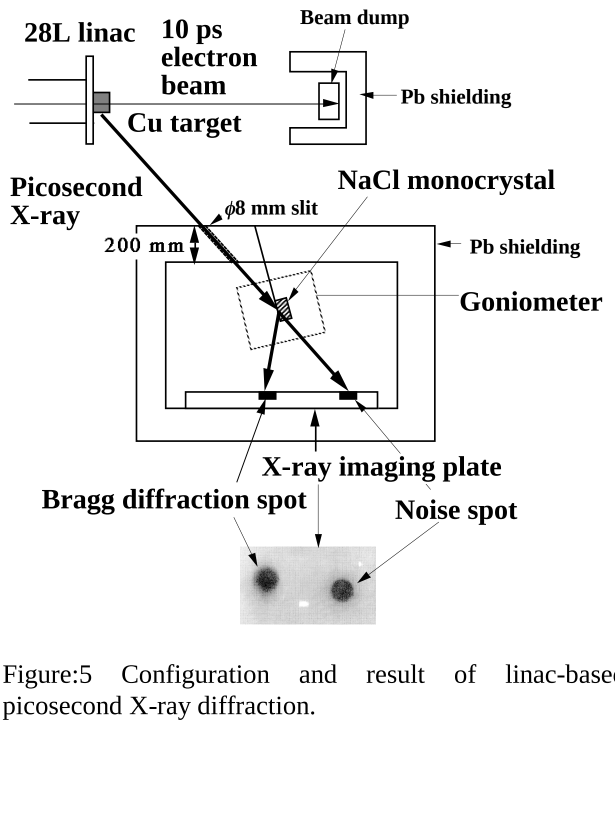

Figure:5 Configuration and result of linac-based picosecond X-ray diffraction.

5 CONCLUSION

We constructed the synchronized femtosecond electron linac and femtosecond T^3 laser system. Futher, the new laser photocathode RF electron gun was introduced and 440 fs eletron single pulse with the low emitance was produced. The laser wakefield acceleration and femtosecond X-ray generation via Thomson scattering were experimentaly verified. The subpicosecond pulse radiolysis system for radiation chemistry using the T^3 laser and the new electron gun is under construction. The new pump-and-probe analysis has been proposed by several types of femtosecond quuantum beams to investigate ultrafast processes in radiation-induced matters such as atomic and molecular dynamics. As the first step, the X-ray diffraction by the picosecond electron-induced X-rays was successfully carried out. We are going to proceed to a new femtosecond quantum beam science and pump-and-probe analysis to visualize ultrafast and microscopic phenomena in matters

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