The 11th Symposium on Accelerator Science and Technology, Harima Science Garden City, 1997

Current Status Report of Subpicosecond Electron Linac of NERL of Univ. of Tokyo

Mitsuru UESAKA, Toru UEDA, Koji YOSHI, Hideki HARANO,
Takahiro WATANABE and Kenichi KINOSHITA
Nuclear Engineering Research Laboratory, University of Tokyo
2-22 Shirakata-Shirane, Tokai, Naka, Ibaraki, 319-11 JAPAN

Abstract

The new laboratory of Beam-Material Interaction started this April to promote generation and application of ultrashort quantum beams. 8 research subjects have been accepted and performed in the linac facility in this fiscal year. Coherent transition radiation interferometry is applied to picosecond electron bunch measurement. The results agree with the results obtained by the femtosecond streak camera. The experiment of the laser wakefield acceleration is under way under the collaboration with KEK and JAERI-Kansai. The 18L linac of the twin linacs has been modified for femtosecond X-ray pulse generation via Thomson backward scattering. The laser photocathode RF gun and the chicane-type magentic pulse compressor have been installed. The first experimemt has been carried out in August and September. X-ray diffraction of an ionic nomocrystal (NaCl) was perfomed using subpicosecond X-ray pulse. The low power X-band RF test for the X-band femtosecond linac and the design study of the linac with the laser photocathode S-band RF gun is carried out.

1 Introduction

The new laboratory of Beam-Material Interaction was established at NERL of University of Tokyo this April to promote generation and application of ultrashort quantum beams. 8 research subjects have been accepted and perfomed at the linac facility in this fiscal year. The joint research project on the laser wakefield acceleration [1] is continuing. In the reserach the 18L linac of the twin linacs has been modified for femtosecond X-ray pulse generation via Thomson backward scattering. The laser photocathode RF gun and the chicane-type magentic pulse compressor have been constructed and installed. Here we summarize and introduce the updated research activities related to femtosecond quantum beam research.

2 Femtosecond Electron Pulse Generation at the S-band linac

The major research theme in the project on the laser wakefield acceleration in this fiscal year is femtosecond X-ray generation via Thomson backward scattering between femtoseocnd elctron and laser pulses. 100 fs laser pulse by the T^3 (Table-Top Tera Watts) laser is used. As a counterpart we have to generate femtosecond electron pulse whose pulse width (FWHM) is far less than 1 ps. For this purpose we have decided to modify the 18L linac of the twin linacs. We have moved the 90 kV thermionic eletron gun, the subharmonic buncher and the two prebunchers and installed the new laser photocathode S-band RF gun. Additionally we designed, manufactured and installed the new chicane-type magnetic pulse compressor after the constant gradient travelling-wave-type S-band acceleraing tube. The RF gun was designed and manufactured by KEK, Brookhaven National Laboratory and Sumitomo Heavy Industries. About 10 ps (FWHM) light pulse with tens μJ energy, which irradiates the copper cathode at 10 Hz, is produced by the YLF laser. 6 MW RF power is fed to the 1.6 cell S-band cavity to induce 100 MV/m maximum field gradient. 4.7 MeV, 10 ps (FWHM), 1 nC electron pulse with rather low transverse emittance of 1π mm • mrad in normalized rms is expected to come out. The solenoid magnet is attached to the cavity for transverse emittance compensation against space charge effect. This solenoid magnet is used to make the electrons transport in parallel in the longitudinal direction. The beam spot is about ϕ7 mm. The low emittance elctron beam is accelerated up to 17 MeV and simultaneously its energy profile is modurated for magnetic pulse compression in the accelerating tube where the maximum field gradient is 8.5 MV/m. The chicane was designed so as to compress the 10 ps pulse to 200 fs (FWHM). The inner structure of the acceleration tube was inputed to SUPERFISH to calculate electromagnetic field components of the travelling wave. The data of the electromagnetic components was transfered to PARMELA. Simulation of transport, acceleration, energy modulation and magnetic pulse compression of the electrons was perfomed by PARMELA. The schematic drawing of the modified 18L linac is depicted in Fig.1. Calculated result of the longitudinal phase space electron distribution and the pulse shape after the chicane is shown in Fig.2. 200 fs (FWHM) electron single bunch generation was confirmed by the simulation [2].

The installation of the RF gun, the chicane and other components was finished in July. Since then RF power aging of the RF cavity of the gun was carried out. The beam test started in the beginning of August. The pulse

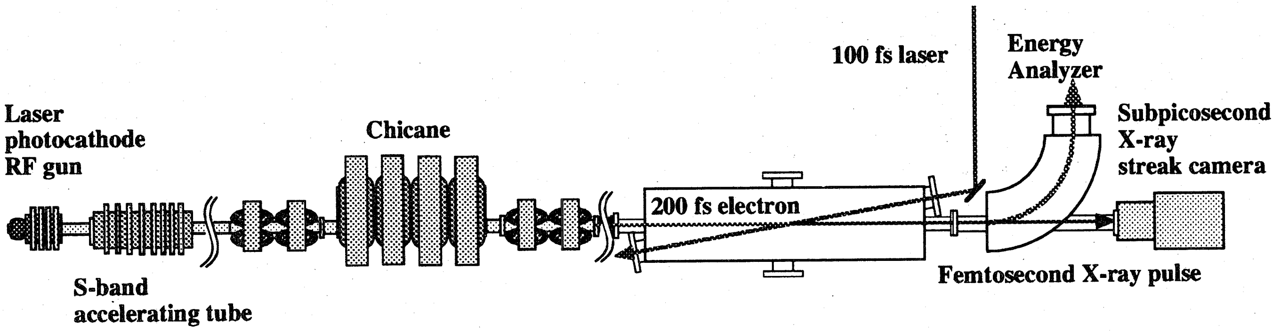

Fig.1 Schematic drawing of the modified 18L linac

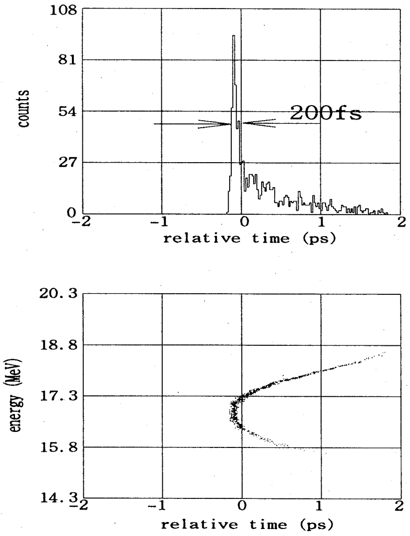

Fig.2 Longitudial phase space electron distribution and pulse shape after the chicane calculated by PARMELA

shape of the compressed beam is measured by the femtosecond streak camara (FESCA-200, HAMAMATSU PHOTONICS) via Cherenkov radiation in Xe-gas. This experiment and measurement will be performed till mid-September. Updated experimental results are introduced in the presentation. Femtosecond X-ray pulse generation via Thomson backward scattering and mesurement by the X-ray subpicosecond streak camera are planned this November. Coherent transition radiation interferometry is also adopted to obtain the 200 fs compressed pulse shape and its result is compared with that by the femtosecond streak camera. For the purpose a new Michelson interferometer is designed. This measurement and comparison will be done this December.

3 Pulse Shape Measurement by Coherent Transition Radiation Interferometry

There are two methods to evaluate pulse shape of subpicosecond electron bunch. The first one is to measure Cherenkov radiation or optical transition radiation emitted by the electron bunch by the femtosecond streak camera [3] while the second one is the coherent far-infrared transition radiation interferometry [4]. It is important to compare the results by the two methods in order to confirm the precision of both methods. This task was carried out under the collaboration with Prof.M.Ikezawa, Dr.Y.Shibata and their research group of the Res. Inst. Sci. Measurement of Tohoku University this May. We used the 28L linac where the achromatic arc-type magnetic pulse compressor is installed. We used the Martin-Pupplet interferometer with the wire-grid polarizing beam spritters (ϕ10 μm wires with 25 μm spacing) and liquid-He-cooled Si bolometers. At first we obtained the interferogram of the light intensity of interfered two transition radiation pulses as a function of the moving mirror position. Next we calculated the power spectrum the transition radiation by the inverse Fourier transformation. Then we substracted the power spectrum of the incoherent components from the total spectrum to get the product of the longitudinal and transverse bunch form factors. The transverse bunch form factor was evaluated by the measurement of the transverse beam size. Finally the Kramers-Kronig relation gives the longitudinal bunch distribution from the longitudinal bunch form factor. In the experiment the longitudinal bunch distribution was controlled by tuning energy modulation of the bunch in the second accelerating tube for magnetic pulse compression. We chose 1.5, 3, 10 ps (FWHM) pulse widths and performed the comparison between the streak camera and coherent trasition radiation interferometry measurements. Pulse shapes of 1.5 ps bunch obtained by the streak camera and interferometry are shown in Figs.3, 4, respectively. The figures indiactes nice agreement. Nice agreement was also confirmed in case of 3, 10 ps bunches. Thus the validity of the both methods has been confirmed up to 1.5 ps (FWHM) short bunch [5]. The next subject is to check it for 200 fs (FWHM) bunch as mentioned in Sec.2.

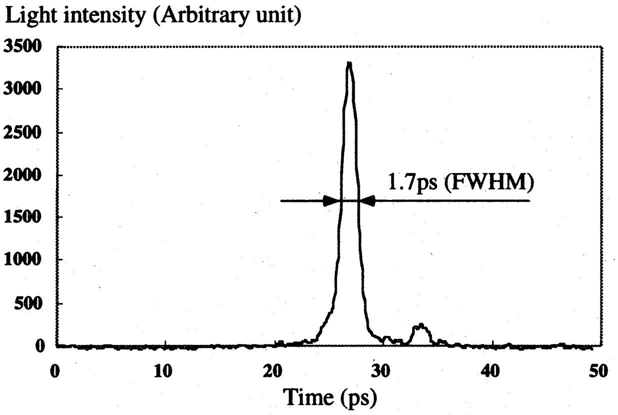

Fig.3 Pulse shape of 1.5 ps bunch obtained by the femtosecond streak camera.

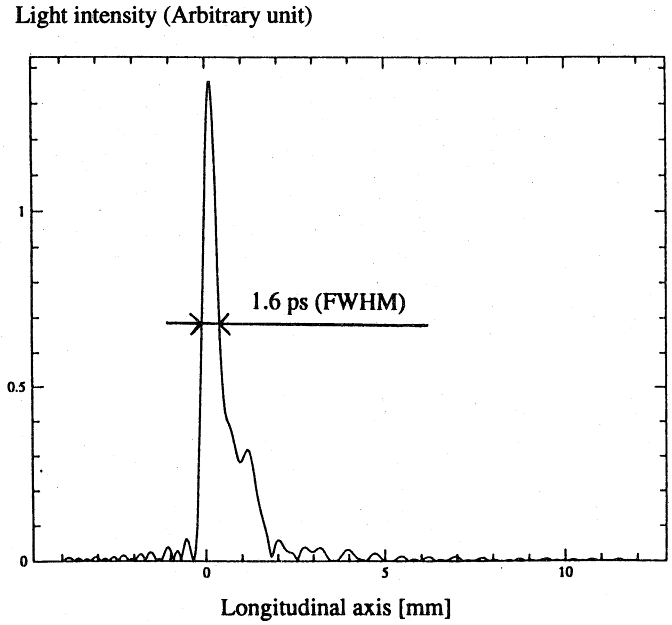

Fig.4 Longitudinal bunch distribution constructed by the coherent transition radiation interferometery.

4 Ultrafast X-ray pulse

Subpicosecond X-ray pulse was generated by irradiating 30 μm thick copper foil by subpicosecond electron single bunch from the 28L linac. Kα X-rays of 8.1 keV, 1.54 nm were picked up and X-ray diffraction was performed for the ionic monocrystal of NaCl. The X-ray diffraction image was obtained on the X-ray image plate (by the courtesy of Dr.N.Niimura of JAERI). As the next step the expriment of the pulse-snapshot X-ray diffraction [6] is planned next year to visualize ultrafast movement of atoms. This pulse-snapshot technique is a pump-and-probe-like analysis for ultrafast radiation induced phenomena in matter using synchronized different ultrashort pulses where the snapshot of the phenomena is obtained at each delayed time between the two pulses. Here a monocrystal such as NaCl, NaI, KBr, Si, GaAs etc is irradiated by subpicosecond far-infrared coherent synchrotron radiation (pump) to indude movement of atoms and then the monocrystal is irradiated by subpicosecond X-ray pulse (probe) to get three dimensional snapshot of atoms via the X-ray diffraction. The irradiatio of the two pulses is repeated till the clear X-ray diffraction image is obtained. Since the same electron single bunch generates the two pulse and the delay time is controlled by changing the optical length of the coherent synchrotron radiation, there is no time jitter between the two pulses. Finally the ultrafast movement is visualized by computer graphics.

5 X-band Femtosecond Linac

The design study of a new X-band femtosecond linac system with a laser photocathode S-band RF gun is performed [7]. It is confirmed by PARMELA that 200 fs (FWHM) electron single bunch with 1 nC is produced. Solenoid magnet system is rather simplified. On the other hand, the reliability and stability of low power X-band RF components are under invetigation [8].

References

[1] K.Nakajima et al., Proc. of the 17th Particle Accelerator Conf., Vancouver, 1997 (in press).
[2] K.Kinoshita et al., Proc. of the 11th Symp. on Acceleator Sci. and Tech., Harima, 1997.
[3] M.Uesaka et al., Phys. Rev. E, Vol.50, 1994, pp.3068-3076.
[4] Y.Shibata et al., Phys. Rev. E, Vol.50, 1994, pp.1479-1484.
[5] Y.Shibata, M.Uesaka et al., submitted to Nucl. Instrum. Meth.
[6] M.Uesaka et al., J. of Nucl. Materials, 1997 (in press).
[7] H. Harano et al., Proc. of the 11th Symp. on Acceleator Sci. and Tech., Harima, 1997.
[8] T.Ueda et al., Proc. of the 22th Lin. Accelerator Meeting in Japan, Sendai, 1997 (in Japanese).