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FEMTOSECOND ULTRAFAST QUANTUM PHENOMENA RESEARCH

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Abstract

Femtosecond quantum phenomena research project is proposed at Nuclear Engineering Research Laboratory, University of Tokyo. The research facility consists of an X-band (11.424GHz) femtosecond electron linac, a femtosecond wavelength tunable laser, two S-band (2.856GHz) picosecond electron linacs and measuring equipments. Especially, we aim to generate a 100fs (FWHM) electron single bunch with more than 1nC at the X-band linac. Ultrafast processes in radiation physics, chemistry, material science and microscopic electromagnetic phenomena are going to be analyzed there. The specification of the facility is presented.

1. Introduction

A subpicosecond (700 fs in FWHM) electron single bunch was produced and measured at the S-band linac of Nuclear Engineering Research Laboratory, University of Tokyo, in 1994. Since then electric charge has been enhanced up to 1 nC per bunch. Now the subpicosecond pulse-radiolysis measurement for radiation physics and chemistry is under way. Here we propose the femtosecond ultrafast quantum phenomena research, where both 100 fs (FWHM) electron and laser single pulses are available, as the next project. The facility consists of an X-band (11.424GHz) femtosecond electron linac, an femtosecond wavelength tunable laser, two S-band electron linacs and several diagonostic and analyzing equipments. This facility enables us to measure, analyze and visualize excitation, ionization and relaxation of atoms and molecules and ultrafast process of radiation damage and surface phenomena of materials.

2. Specification of the facility

The specification of the facility is described below. The layout of the machines are shown in Fig.1. The main design parameters are summarized in Table 1.

(i) X-band femtosecond electron linac

We have chosen X-band (11.424GHz) as the main accelerating RF according to the following reason. We think we have already optimized the operation parameters of magnetic pulse compression to produce a subpicosecond single bunch from a 10 ps (FWHM) original bunch at the S-band (2.856GHz) linac[1]. Actually we have developed and validiated the so-called nonlinear energy modulation. Further, measured pulse widths agreed well with numerical results based on the three dimensional particle tracking analysis. This indicates that the beam parameters such as emittance and energy spread which we used are rather reliable. Then we figure out that we have to have a shorter bunch and smaller emittance before the compression in order to produce a 100 fs single bunch. To fulfill the former requirement, we should introduce higher frequency RF, namely X-band (11.424GHz). X-band klystron, accelerating tubes and other components are under development for a future linear collider at KEK and SLAC[2,3,4]. We are to use 40 MW or less RF power and 300 ns or longer pulse duration of the X-band klystron. Two travelling wave acceleraing tubes of $2/3\pi$ mode and constant impedance are used. The length of the regular acceleraing tube is 0.6 m and the field gradient is 40 MV/m at the entrance and 25 MV/m at the exit. The former tube have a buncher section, where the RF phase velocity varies from 0.7c to 0.9c, at the entrance. The final energy is 35 MeV. In order to fulfill the latter reqiurement, we have chosen the 200 kV thermionic electron gun and to produce the peak current of 100 A with the pulse width of 200 ps (FWHM) by using the fast grid pulser. We found by using PARMELA that we have to use two subharmonic bunchers of 476 MHz and 2.856 GHz to get a single bunch without satellites. Pulse width and electric charge per bunch were calculated to be 1 ps and 1 nC, respectively. Finally, the achromatic arc-type magentic pulse compressor achieves a 100 fs single bunch.

(ii) Femtosecond wavelength tunable laser

The laser is used as a probe light source in the light absorption pulse-radiolysis. Main oscillater and amplifier are Ti-sapphire which produces 100 fs light pulses of the wavelengh of 720-850 nm. The wavelength can be expanded from 700 nm to 1.1 μm by using the wavelengh converter. The repetition rate of laser pulses is tuned to be 79.3 MHz by the lock-to-clock. The single pulse operation is also available by the pulse selector of pockel cells synchronized by the main trigger system.

(iii) High charge S-band electron linac

It is important to study fast quantum phenonema not only in the femtosecond time domain but also in the picosecond and nanosecond time domains to understand their whole process. From point of view of measurement with high signal-to-noise ratio, it is beneficial to use an S-band linac for the study in the picosecond and nanosecond time domains since it can obtain more electric charge per bunch than an X-band linac. For the purpose we plan to use a 200 kV thermionic electron gun to get as much charge per bunch as 5 nC at the first S-band linac. It consists of the 200 kV gun, the 476 MHz subharmonic buncher, two travelling wave accelerating tubes and the achromatic arc-type magnetic pulse compressor so that the wide-ranged pulse structures such as 500 fs - 10 ps single bunch and 5 μs macro pulse are available.

(iv) Cherenkov radiator S-band electron linac

The second S-band linac is used as a Cherenkov radiation source in the light absorption pulse-radiolysis. Its specification is the same as the first S-band linac except the 90 kV gun which is the same one as the current machines have. Further, an advanced RF electron gun with a laser photocathode is to be tested at the second linac.

(v) RF control and trigger system

476 MHz has been chosen as the main RF generated by the master oscillator. S-band RF (2.856MHz) and X-band RF (11.424GHz) are generated from 476 MHz RF by the frequency multipliers. On the other hand, 79.3 MHz RF which is 1/6 of 476 MHz is generated by the frequncy devider to synchronize the femtosecond laser with the linacs. A trigger pulse is generated so as to be synchronized with a specified 476 MHz RF phase and fed to drive the electron guns, the femtosecond laser and the streak camera.

(vi) Pulse width measurement eqiupments

A new femtosecond streak camera with the time resolution of 50 fs is now under development. After the development is completed, we plan to introduce it for both on-line pulse diagnosis and femtosecond pulse radiolysis. We are also going to construct the Michelson interferometer for off-line pulse diagonosis via optical transition radiation[5].

(v) Analyzing equipments

The following analyzing eqiupments plan to be installed for wide-ranged utilization; sample temperature control system, electron spin resonance analyzer (ESR), electrospectroscopic chemical analyzer (ESCA), Fourier Transform Infrared Spectrometer (FTIR), time-resolved plasma monochrometer and mass-spectrometer, high power wide-ranged wavelengh tunable laser with narrow bands etc.

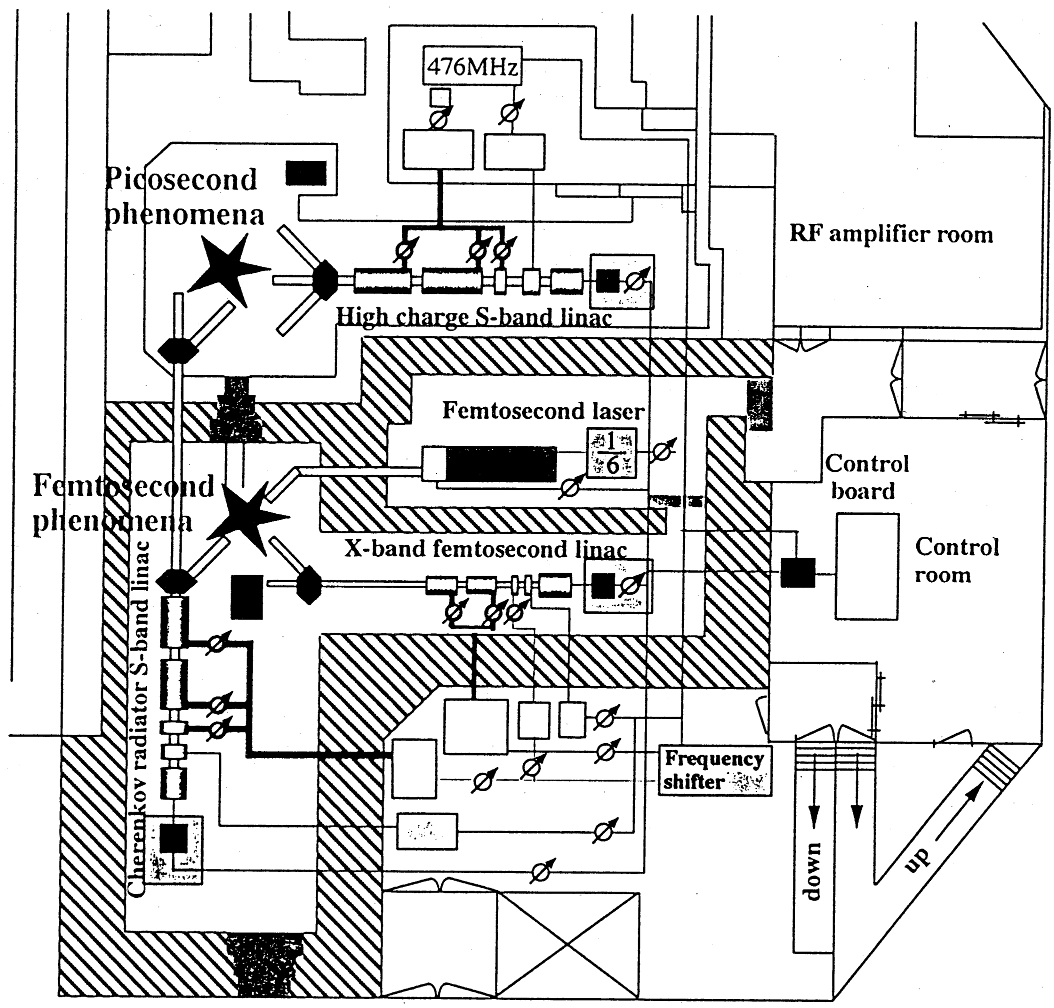

Fig. 1 Layout of the facility for the femtosecond ultrafast quantum phenomena research

Table 1 Main design parameters of the facility

X-band femtosecond electron linac

Pulse width (FWHM)	100 fs with compression 1 ps without compression
Electric charge	1 nC per bunch
Maximum energy	35 MeV
Electric gun	200 kV thermionic 10 A at peak 200 ps (FWHM)
Bunch mode	single bunch
Repetition rate	50 pps
Jitter	< 1 ps
Subharmonic	476 MHz (coaxial)
Buncher	2.856 GHz (nosecone)
Accelerating tubes	two tubes travelling wave 2/3π mode 0.6 m for regular 40 - 25 MV/m
Buncher	0.7c -> 0.9c
Klystron	< 40 MW > 300 ns
Achromatic arc-type magnetic pulse compressor	

Femtosecond wavelength tunable laser

Pulse width	100 fs
Wavelength	700 - 1100 nm
Repetition rate	79.3 MHz

High charge S-band electron linac

Pulse width (FWHM)	500 fs with compression 10 ps without compression < 5 μs for macro-pulse
Electric charge	5 nC per bunch
Maximum energy	35 MeV
Eletron gun	200 kV thermionic
Klystron	10 MW 5 μs 50 pps
Achromatic arc-type magnetic pulse compressor	
Bunch mode	single and multi

Cherenkov radiator S-band electron linac

Electron gun	90 kV thermionic Laser photocathode RF gun

3. Summary

Current design of the facility for the femtosecond ultrafast quantum phenomena research is described. We are going to evaluate three dimensional wake field in the buncher and regular cells at the X-band linac. Detailed design has also started. We have submitted the proposal to the government via University of Tokyo. The construction of the facility is expected to be done in 1996 -1997.

Acknowledgement

The authors would like to thank the following researchers for their technical advises; Drs. H.Mizuno, T.Higo, H.Kobayashi, S.Ohsawa, S.Fukuda, A.Ogata, H.Nakajima and Y.-J.Choi of KEK and Dr. G.A.Loew of SLAC.

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