THE LEBRA 125 MEV ELECTRON LINAC FOR FEL AND PXR GENERATION

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Abstract

A 125MeV electron linac has been constructed at Laboratory for Electron Beam Research and Application (LEBRA) in Nihon University for Free Electron Laser (FEL) and Parametric X-ray (PXR)[1] generation. Electron bunches of 3 - 4 psec width formed at the injector are compressed to within 1 psec during passing through the magnetic bunching system. Peak current of the electron beam injected to the FEL system is expected to be about 50 A. FEL lasing has been achieved at the wavelength range from 0.9 to 6 μm. Estimated peak power of the extracted FEL light pulse is about 4 MW. Applied researches using the FEL started last autumn. Preliminary experiment for the PXR generation has been proceeded. First light of the PXR is observed at April in this year.

INTRODUCTION

The specifications of the electron linac are listed in Table 1. The beam injection system and the regular accelerator sections of the linac were moved from KEK Photon Factory positron injector linac as a part of collaboration on development of a high quality electron linac. Schematic layout of the accelerating structures and RF system are shown in Fig.1.

FEL beam line has been installed to feed near infrared laser for application users [2]. To improve FEL gain, magnetic bunch compressor has been adopted.

To generate monochromatic X-ray, PXR beam line has been installed next to FEL beam line. Several interesting results are obtained.

LINAC

The electron linac has a conventional configuration. It consists of a DC electron gun with a dispenser cathode, a prebuncher which is a 7-cell travelling wave structure, a buncher which is a 21-cell travelling wave structure and three 4-m long normal accelerator sections.

Table 1:Specifications for LEBRA 125MeV linac.

Accelerating rf frequency	2856	MHz
Klystron peak output rf Power	30	MW
Number of klystrons	2	
Electron energy	30~125	MeV
Energy spread (FWHM)	0.5~1	%
Macropulse beam current	200	mA
Macropulse duration	20	μsec
Repletion rate	12.5	Hz

RF System

Two klystrons feed rf power of approximately 20MW peak and 20μsec pulse duration each to accelerating structures. Phase of the rf fed to each component is controlled independently.

Output RF phase of the solid state RF amplifier and the klystron drifts with a room temperature variation. Since RF amplifier is operated in pulse mode, RF phase change

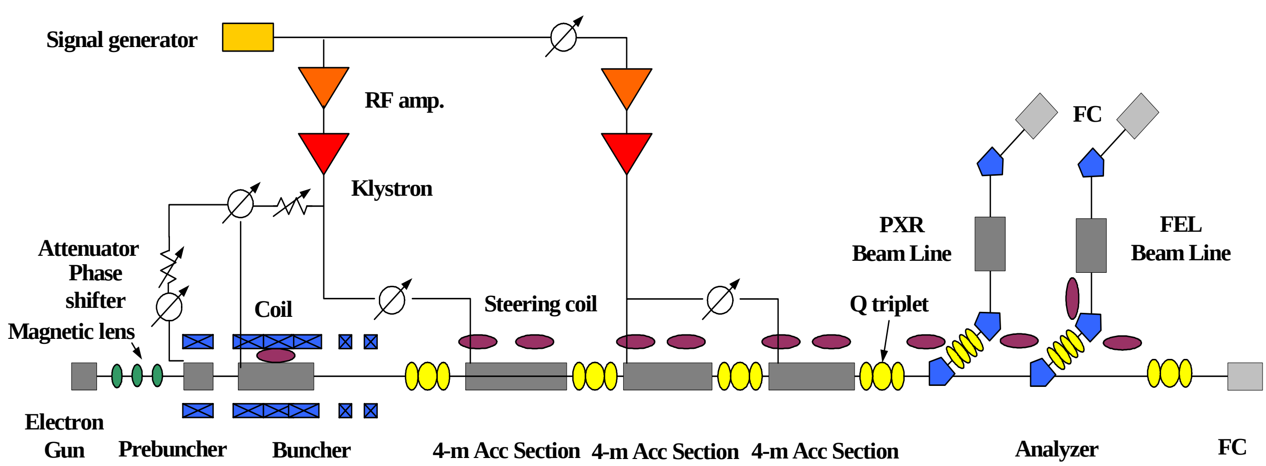

Figure1: Schematic layout of the LEBRA linac and the FEL and the PXR beam line.

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during the pulse duration. Phase drift is compensated by using a slow feedback circuit and feed forward compensation is adopted for phase deviation during the pulse duration. Both feedback and feed forward signals are combined and fed to the fast phase shifter installed just upstream of the RF amplifier. Phase stability is achieved within 0.5 degree both long term and during the pulse duration [3].

Magnetic Bunch Compression

Last two accelerator sections are connected to the second klystron as shown in Fig.1. Accelerating phase of the third accelerator section is controlled independently of the second one using a phase shifter attached in the RF feed line of the third accelerator section. Then, the electron beam can be accelerated to same energy by various combination of the phase. Accelerating energy E without beam loading term in this section is described as follow.

$$
\begin{aligned}
E &= E_0(\cos(\phi) + \cos(\phi + \Delta\phi)) \\
&= 2E_0 \cos(\phi + \frac{\Delta\phi}{2}) \cos\Delta\phi
\end{aligned}
.
$$

Where E_0 is the maximum accelerating energy for each accelerator section, ϕ is the accelerating phase of the second accelerator section dependent on the klystron output phase and $\Delta\phi$ is the relative phase between the second and the third accelerator sections. Electron energy within a bunch is transformed in the first order approximation as

$$
\begin{aligned}
\delta E &= \delta E_0 + \frac{\partial E}{\partial \phi} \delta\phi_0 \\
&= \delta E_0 - 2E_0 \sin(\phi + \frac{\Delta\phi}{2}) \cos(\Delta\phi) \delta\phi_0
\end{aligned}
$$

where $\delta\phi$ and δE are phase and energy relative to the central position and mean energy of the bunch. Suffix 0 of these variables means initial value. Even if the combination of the phase that gives the same energy, the effect on the energy distribution is different. Therefore we can handle the distribution of the electrons in the longitudinal phase space. Injection beam line to the FEL is a 90 degrees achromatic bending system as a momentum analyzer. It consists of two 45 degrees bending magnets, four quadrupole magnets and a momentum slit. In the case of achromatic bending, relative phase $\delta\phi$ is transformed as

$$
\delta\phi = \delta\phi_0 + 2\rho(\theta - \sin\theta) \frac{2\pi}{\lambda} \frac{\delta E}{E_{total}} .
$$

where ρ and θ are a orbital radius and bending angle of the bending magnets, λ is a wavelength of the accelerating RF in free space and E_{total} is an electron mean energy at the exit of the linac. If we select proper phase combination, which brings the required accelerating energy, bunch compression mechanism will be realized. By the bunch compression, about 3 psec of the bunch length at the exit of the linac becomes 1 psec at the entrance of the undulator[4]. Peak current of the electron beam also increases about three times. In the present operation condition, the peak current is estimated about 30 A. And it will be increased to 50 A or more in near future.

FEL

The undulator consists of a planar Halbach type permanent magnet, where the electron beam is wiggled in the vertical plain. The specifications of the FEL system are listed in Table 2. At the beginning of the FEL experiments, dielectric or Au coated quart based mirrors were used. Because of the poor thermal conductance of the quart, coated material was frequently damaged according to increasing the optical power at lasing. To avoid these kinds of trouble, cupper based silver coated mirrors are used. Optical power is extracted through the small hall excavated at the mirror center. Laser light beam extracted from the optical cavity is parallelised using beam expander that consists of spheroidal and parabolic mirrors and transmitted to the experimental rooms through the vacuum ducts.

Lasing of the LEBRA FEL has been achieved from 0.9 to 6 μm of wavelength. Typical FEL signal detected using an InSb photo detector, which indicate macro pulse structure is shown Fig. 3. Duration of the electron beam pulse is about 18 μsec, FEL is saturated after 8 μsec from start of the electron beam pulse and continued about 10 μsec. Output FEL energy per macro pulse is dependent on wavelength and beam current. Maximum power is

Table 2: Parameters for LEBRA infrared FEL system

Resonator length, L	6.718	m
Rayleigh range	1.467	m
Coupling hall	0.3	mm
Undulator period	48	mm
Undulator length	2.4	m
Number of periods	50	
Maximum K (rms)	1.35	

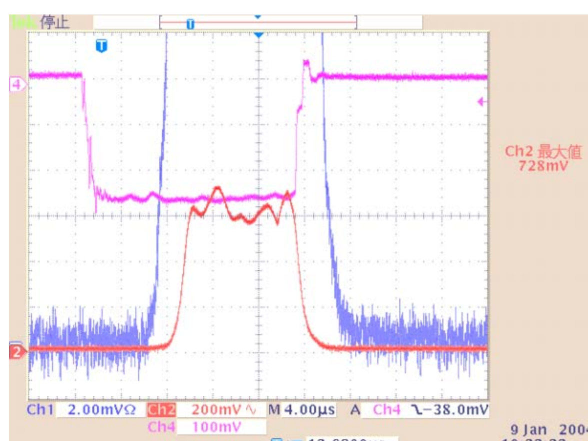

Figure 2: Typical waveform of the electron beam (upper trace) and FEL (lower trace).

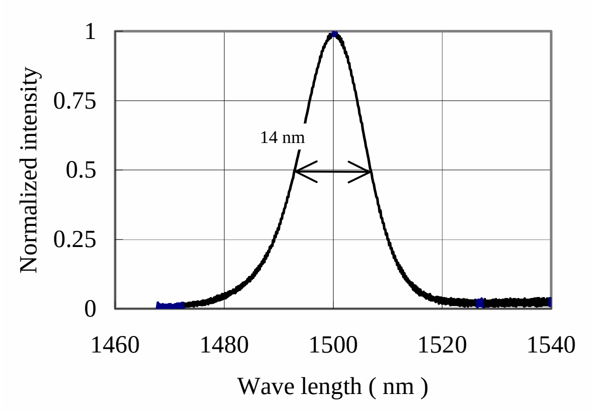

Figure 3: Spectrum of the FEL. Spectral width is about 14 nm.

accomplished wavelength of from 2 to 3 μm. Maximum energy per macro pulse obtained until now is 30 mJ.

Spectra were measured at up to wavelength of 1500nm by means of a monochrometor and an InGaAs photo diode array. Typical one is shown in Fig. 3. Spectral width is about 14 nm (FWHM) at mean wavelength of 1500 nm. Assuming Gaussian shape wave packet, about 70 μm (FWHM) of optical pulse length is deduced from inverse Fourier transformation from the spectrum. This value agrees well with what was obtained from the autocorrelation experiment[4]. If maximum energy of 30mJ per macro pulse of 10μsec converts simply, peak power is about 4 MW

Experiments of applied researchers started at last autumn.

PXR

The PXR beam line is installed parallel to the FEL beam line as shown in Fig. 1. The PXR system consists of two silicon single crystals. One of them is the radiator for PXR and another one is a reflector for X-rays. The reflector is movable parallel to the electron beam axis in order to extract X-rays with any defined wavelength through the fixed output port[5].

First light of the PXR was observed at April 14, this year. X-rays signal was detected by means of ionization chamber set at the output port. X-rays energy range in present setup is from 5 to 20keV. In principle, PXR has the spatial distribution with the energy gradient in the reflection plain. From the preliminary measurement, relation between X-ray direction and energy at incident electron energy of 100MeV is 0.7%/mrad. A photograph in which the Br-Kα absorption edge is seen as the boundary of light and darkness is taken by direct exposure at output port with the Polaroid film shown in Fig. 5. XAFS appears in the photograph but cannot be seen clearly in this figure.

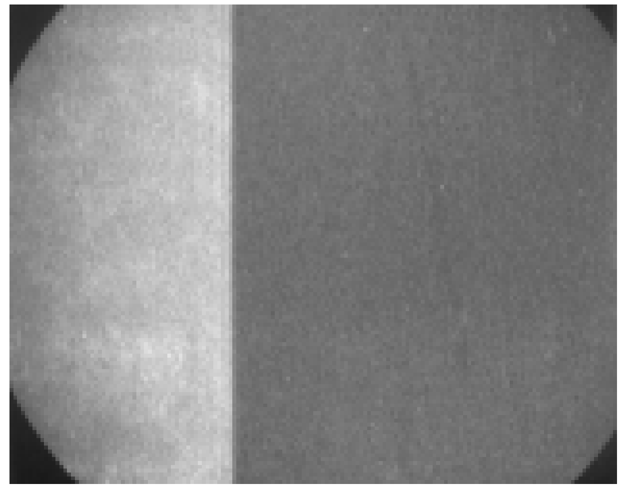

Figure 4: A photograph in which the Br-Kα absorption edge (13.5keV)is seen as the boundary of light and darkness.

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