FAR-INFRARED FREE ELECTRON LASER BASED ON THE L-BAND LINAC AT OSAKA UNIVERSITY

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Abstract

The far infrared FEL based on the L-band linac at ISIR, Osaka University is being modified so that the laser wavelength is extended to the longer wavelength region. After the wiggler and the bending magnets were remodeled and the vacuum chambers for them were replaced, we have observed laser oscillation at wavelengths from 21 to 164 μm.

1 INTRODUCTION

The far infrared free electron laser (FEL) based on the L-band linac is now being developed at the Institute of Scientific and Industrial Research (ISIR), Osaka University [1]. The first lasing was obtained at wavelengths from 32 to 40 μm in 1994 [2,3]. In the next step, we are modifying the FEL system suitable for user experiments. This modification includes remodeling of the wiggler and two bending magnets, and the replacement of vacuum chambers for the bending magnets and the mirror holders for the optical resonator. As reported previously [4,5], the wiggler was modified from a fixed gap width to a variable one. Then magnet gaps of the bending magnets have been widened and the vacuum chambers for the two bending magnets have been replaced with new ones with larger cross-sections in order to reduce the diffraction loss in the optical resonator.

After the remodeling, we have observed FEL oscillation at wavelengths from 21 up to 164 μm, which is the longest wavelength so far obtained in the experiments based on RF linacs. In this paper, we report the results for the FEL experiments.

2 ACCELERATOR AND THE FEL

The L-band linac has the injection system composed of two 12th and one 6th sub-harmonic bunchers (SHBs), a pre-buncher and a buncher in order to produce an intense single bunch beam. When FEL experiments are conducted with multi-bunch mode, the electron beam with a peak current of 600 mA is injected from a thermoionic electron gun into the SHB system. In this case the second 12th and the 6th SHBs are powered. The characteristics of the electron beam are listed in Table 1. The energy spectra are shown in Figure 1. We used an electron gun with a cathode area of 3 cm^2 (EIMAC, YU-156), which is usually used in operation of the linac, and one with a cathode area of 0.5 cm^2 (EIMAC, Y-646B) for the experiments at the lower beam emittance.

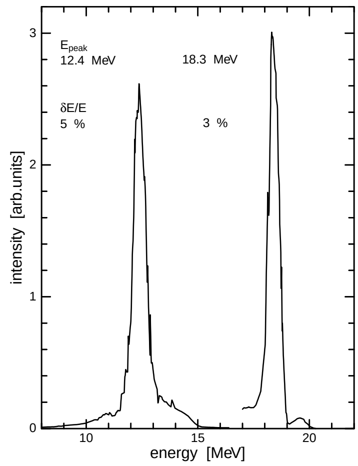

Figure 1: The energy spectra of the electron beam from the L-band linac.

Table 1 Main parameters of the electron beam

Energy	12-19 MeV
Accelerating frequency	1300 MHz
Bunch spacing	9.2 ns
Charge / bunch	2 nC
Peak current / bunch	50 A
Bunch length	20-30 ps
Macropulse length	1.8 μs
Normalized emittance	
Y-646B	80π mm mrad
YU-156	200π mm mrad

The electron beam is transported through an achromatic bend to the FEL system. The main parameters of the FEL system are listed in Table 2. The wiggler is a planer type. The magnet gap of the wiggler is variable from 30 to 120 mm, for which K = 0.013 - 1.472. By changing the electron energy from 12 to 19 MeV, it is possible to cover the FEL wavelengths from 20 to 170 μm for the fundamental oscillation, and from 6 to 56 μm for the third harmonic.

In the wavelength region longer than 100 μm, the diffraction loss in the vacuum chambers of the optical resonator can not be disregarded. After replacing the vacuum chambers in the two bending magnets, the calculated diffraction loss became considerably.

Table 2 Main parameters of the wiggler and the optical resonator

Wiggler	
Magnet	Nd-Fe-B
Length	1920 mm
Number of periods	32
Magnet gap	30 – 120 mm
K-value	0.013 – 1.472
Optical resonator	
Cavity length	5532 mm
Radii of mirrors	
M1	3384 mm
M2	2763 mm
Rayleigh range	915 mm
Waist radius	3.4 mm (at 40 μm)

3 LIGHT DETECTION SYSTEM

Laser light was taken out from the optical resonator through a hole of the front mirror 3 mm in diameter, and led through a vacuum window, which is either a KRS-5 plate 5 mm thick or a single crystal quartz plate 2 mm thick. The light is then transported in the air to the measurement room using plane and concave mirrors coated with gold. The intensity of the light was measured with a Ge:Be or Ge:Ga detector cooled with liquid helium. Teflon sheets were used as an attenuator of the light at relatively higher intensity. In the measurement of the spectra of the light, a grating type monochromator was used for wavelengths shorter than 90 μm.

The spectral sensitivity of the Ge:Be detector extends from 20 up to 52 μm and the highest sensitivity is around 40 ~ 45 μm. On the other hand, the Ge:Ga detector has the highest sensitivity around 105 μm and the sensitivity ranges from 50 μm to about 160 μm. For each kind of detector, we used two detectors; one is a so called slow detector which has a relatively high detection sensitivity but has a relatively slow time response, and the other is a fast detector for measuring the time evolution of FEL light. We have measured the time resolution of the fast Ge:Be detector and the fast Ge:Ga detector. Those are 170 ns and 110 ns (FWHM), respectively.

The transmittivity of light through the KRS-5 plate decreases very much above 45 ~ 50 μm, while that through the single crystal quartz plate rises at about 50 μm and is relatively high in the longer wavelength region. Therefore we used the KRS-5 window for measurement below 50 μm and the quartz window above 50 μm.

4 EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1 Oscillation experiments below 50 μm

We conducted experiments at an electron energy of 18.3 MeV. We used the Y-646B electron gun. The wavelength of laser light is determined from the electron energy and the K-value of the wiggler. Figure 2 shows the gain as a function of the wavelength which was derived from the time evolution of laser light measured with the fast Ge:Be detector [3]. The light wavelength was varied by changing the wiggler gap. Since the sensitivity of the detector is practically zero above 60 μm, we have assigned laser light corresponding to that of wavelengths longer than 50 μm for the fundamental to the third harmonic. The FEL gains thus obtained for the fundamental and for the third harmonic are shown by the filled circles and the open squares, respectively, in the Figure 2. The shortest wavelength obtained in the experiments is 21 μm for the third harmonic oscillation.

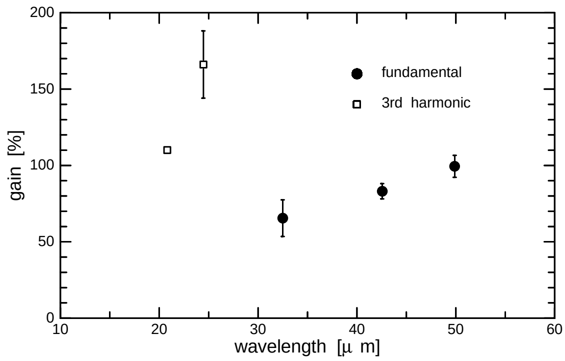

Figure 2: FEL gain as a function of the wavelength below 50 μm. The data points denoted by the filled circles and the open squares are assigned to the fundamental oscillation and third harmonic oscillation, respectively.

4.2 Oscillation experiments above 50 μm

Experiments at the longer wavelength were conducted at electron energies of 12.4 ~ 14.4 MeV. We used the Y-646B or the YU-156 electron gun in these experiments. Laser light coming through the quartz window was detected directly or through the monochromator with the Ge:Ga detector. With the combination of the quartz window and the Ge:Ga detector, the detectable range of light was from 50 μm to about 160 μm. Figure 3 shows the gain of FEL as a function of the wavelength which was also derived from the time evolution of laser light measured with the Ge:Ga detector. The wavelengths were derived by calculation from the electron energy and the K-value of the wiggler. The electron energy and the K-value were calibrated with the wavelengths measured with the monochromator. The gain values denoted by the filled circles and the filled triangles were obtained with the electron gun YU-156 and those denoted by the open diamonds were obtained with Y-646B. Values of the normalized emittance of the electron beams measured for YU-156 and Y-646B were 200 and 80 π mm mrad, respectively, as shown in Table 1. Although Y-646B has higher brightness, the measured values of the gain of YU-156 are higher in the long wavelength region.

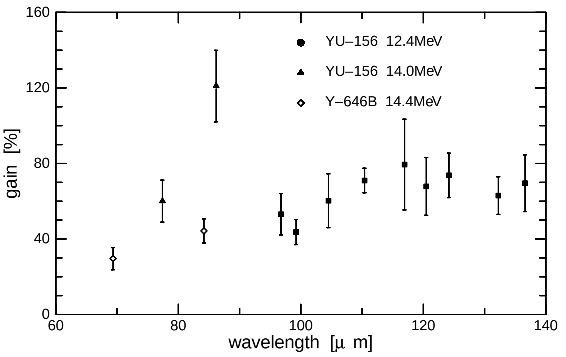

Figure 3: FEL gain as a function of the wavelength above 50 μm. The gain values denoted by the circles and the triangles were obtained at an electron energy of 12.4 and 14.0 MeV using the electron gun YU-156, respectively, and the open diamonds were obtained at 14.4 MeV using the electron gun Y-646B.

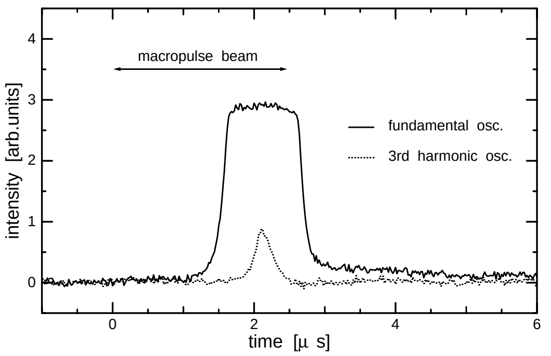

Figure 4: The time spectra of the laser light from the FEL operated at a wavelength of 164 μm measured with the fast Ge:Ga detector. The solid and the dotted lines are for the fundamental and the third harmonic oscillations, respectively. Saturation of the FEL signal for the fundamental oscillation is not that of the FEL oscillation but that of the detector.

Recently, since we optimized timing between the RF pulse of the buncher and that of the accelerating waveguide, the macropulse length of the RF available to the FEL oscillation was widened from 1.8 to 2.5 μs. Thereafter we observed simultaneously the oscillation at wavelengths of 164 and 55 μm, which are the fundamental and the third harmonic oscillation, respectively. Figure 4 shows the preliminary data of the time spectra of the oscillation. The fundamental oscillation is quite stable, but the third harmonic is unstable. The wavelength of 164 μm is the longest wavelength ever obtained with the FELs based on RF linacs.

5 CONCLUSION

In the experiments after the remodeling of the wiggler, the following results were obtained. Lasing was observed at wavelengths from 32 to 164 μm for the fundamental oscillation and from 21 to 55 μm for the third harmonic. The maximum FEL gain observed was about 120 % for the fundamental oscillation and about 160 % for the third harmonic.

Further improvements of the FEL are going on. The mirror holders for the optical resonator are being replaced with new ones, in which larger mirrors will be installed. An evacuated optical transport line from the FEL to the measurement room will be installed soon. We are developing the computer control system for the FEL including the magnets in the beam transport line from the linac.

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