OPERATION OF FIR-AND UV-FEL FACILITIES AND FEL BEAM SHARING TO USER'S ROOMS AT THE FELI

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SUMMARY

Four FEL facilities FEL-1, FEL-2, FEL-3 and FEL-4 achieved lasing at FELI in Oct. 1994, in Feb. 1995, in Dec. 1995 and in Oct. 1996, respectively. Two IR facilities FEL-1 and FEL-2 are open for users to supply several MW-level FELs covering the wavelength range of 1-20μm every other week. The maximum average power of the IR-FEL is 2W. Total operation time in 1996 was about 2400 hours. The visible- and UV-facility FEL-3 has broken the world record for the shortest wavelength oscillation of linac-based FELs with a thermionic gun up to 0.278μm. The FEL beams are delivered from the optical cavities to the diagnostics room and four user's rooms (eighteen stations) through the pipe lines using fan-shaped mirrors with a 90°-opening angle.

INTRODUCTION

The FEL facility consists of an S-band, 165-MeV electron linac with a thermionic gun, beam transport (BT) lines and four FEL facilities FEL-1, FEL-2, FEL-3 and FEL-4 as shown in Fig. 1. Each FEL facility consists of an undulator, an optical cavity and an optical pipeline. FEL-1, FEL-2 and FEL-3 were designed in 1993 and 1994 to cover the wavelengths from 0.3μm to 22μm. FEL-4 was designed in 1995 to cover the wavelengths from 20μm to 80μm.

The 165-MeV linac consists of the 6-MeV injector [1] and seven ETL type accelerating waveguides [2]. The seven accelerating waveguides with a length of 2.93m is of linearly narrowed iris type to prevent beam blow up (BBU) effects at high peak current acceleration.

The injector is composed of a 120-kV thermionic triode gun, a 714-MHz prebuncher, a 2856-MHz standing wave type buncher and focusing solenoids. The axial field keeping the beam radius constant is calculated from the K-V equation.

The gun with a dispenser cathode (EIMAC Y646B) usually emits 500-ps pulses of 2.3A at 22.3125MHz or at 89.25MHz. The grid pulser was manufactured by Kentech Instruments, Ltd., U.K. These pulses are compressed to 60A10ps by the prebuncher and the buncher.

The electron beam of the FELI linac consists of a train of several picosecond micropulse repeating at 22.3125MHz or at 89.25MHz. The train of the micropulse continues for 24μs (macropulse). The repetition rate of the macropulse is 10Hz or 20Hz.

Our rf sources are a 714-MHz klystron (1VA88R, 15kW for 20-Hz, 24-μs flat top pulses) for the prebuncher and two 2856-MHz klystrons (E3729, 25MW for 20-Hz, 24-μs flat top pulses per each) for the buncher and seven accelerating waveguides.

The latter klystrons are based on a E3712 klystron, used for 80-MW, 4-μs pulse operation, modified for 25-MW, 24-μs pulse operation [3] [4]. The modulator for the klystron 1VA88R uses MOS-FET modules [5]. However, the modulator for the E3729 klystron consists of 4 parallel networks of 24 capacitors and 24 variable reactors, and it has a line-switch of an optical thyristor stack. The flatness of our klystron modulator for E3729 is 0.067% at 24-μs pulse operation [6]. The 24-μm pulse operation of these modulators were very successful for lasing at visible-and UV-range.

LASINGS AT FIR-,MIR-,VISIBLE-AND UV-RANGE

The operation of the FELI facility was begun in May 1994. The electron beam size and position are always monitored and controlled to pass through the center of accelerating waveguides using screen monitors installed at the inlet and outlet of every accelerating waveguide and quadrupole magnet. Further, using five screen monitors installed in the S-type BT line [7] for each FEL facility, the beam size and position are adjusted along the axis so as to pass through the center of a narrow vacuum chamber inside each undulator.

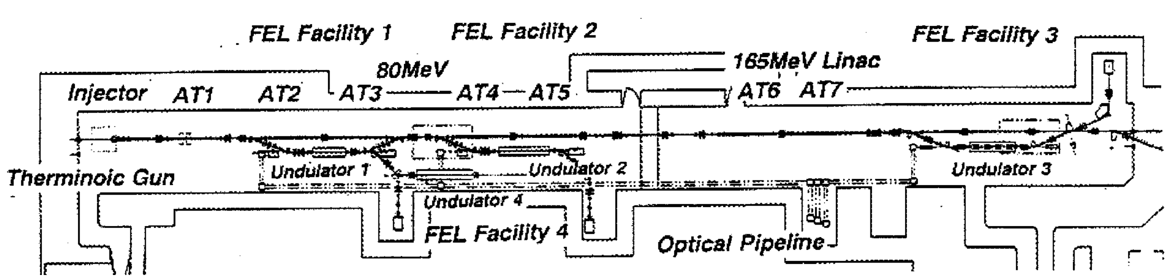

Fig. 1 Layout of 165-MeV linac, S-type BT linacs and four FEL Facilities

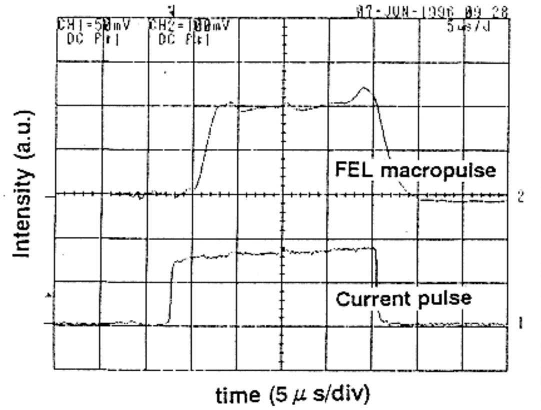

Fig. 2 7.5m FEL macropulse shape and electron current pulse shaped

The beam emittance was measured using three Al-foil OTR beam profile monitors installed in the undulator vacuum chamber. The two profile monitor emittance measurement method is used for its simplicity and short time for data acquisition. The normalized emittance ε_n of a 144-MeV, 60-A electron beam is estimated to be 26π mm mrad [8]. Each Al foil has a 1-mmϕ aperture. The S-type BT line can focus about 80-90% of the electron beam to pass through the aperture.

Each optical cavity is a 6.72-m long Fabry-Perot cavity which consists of two mirror vacuum chambers [9].

The FEL oscillation experiment was begun at FEL-1 (5-22μm) in August and succeeded in lasing at 5-7μm in Oct. 1994 [10]. Fig. 2 shows a 7.5-μm FEL macropulse shape measured with an HgCdTe detector and electron current pulse shape measured with a button monitor [11]. FEL-2 (1-6μm) and FEL-3 (0.23-1.2μm) achieved lasing at 1.88-3.1μm in Feb. [12] and at 0.339-0.353μm and in Dec. 1995, respectively [8].

It has been said that no lasing at ultraviolet wavelengths can be achieved by using an electron linac with a thermionic gun from the wavelength limit due to optical diffraction, because of beam emittance growth in the bunching process from the thermionic gun to the linac. Therefore, the FELI linac was carefully designed to reduce the emittance growth in the bunching process and FEL-3 has broken the world record for the shortest wavelength oscillation up to 0.278μm on June 6, 1996. Fig. 3 shows a 0.278μm FEL spectrum.

Experimental verifications of gain estimates given by Dattoli, et al. [13] and of the criteria on the electron beam quality and wavelength limit due to photon diffraction given by Sprangle, et al. [14] are given by our data on visible- and ultraviolet-FEL oscillations [15].

Peak interacavity power is about 1GW at 0.6μm.

FEL-asist radiation damage to the downstream multilayer mirror was observed after about fifty hours oscillation. Irradiated radiation dosage to multilayer mirrors in optical cavity 3 is estimated to be 0.3 MGray for fifty hours irradiation with thermoluminescence dosimeters (TLDs) [16].

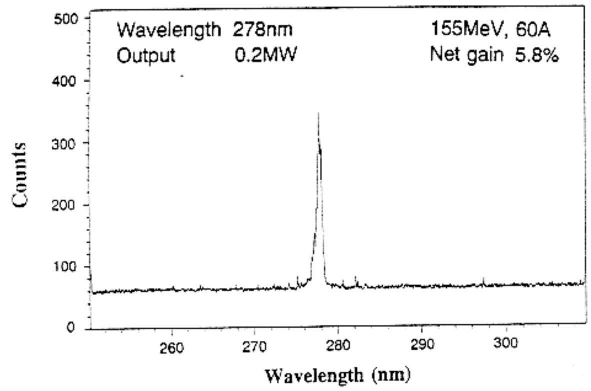

Fig. 3 0.278m FEL spectrum

FEL-4 (20-80μm) including a 2.7-m long Halbach type undulator (λu =8cm, N=30) and a 6.72-m long optical cavity was installed at the 33-MeV beam line, downstream of FEL-1 in Dec. 1996. The FEL beam is delivered from the downstream optical cavity to the user's rooms through the pipeline of FEL-2.

First lasing at 18.6μm was achieved on Dec. 26, within ten hours operation. FEL-4 achieved lasing at 18.6~40μm in Jan. 1997 [18].

FEL BEAM QUALITIES

The FEL micropulse structure depends on the electron micropulse and macropulse structures, the detuning effect of the optical cavity, and the small signal gain of the undulator.

The electron beam of the FEL consists of a train of several picosecond pulses (micropulses) repeating at 22.3125MHz, or to 89.25 MHz although the results presented in this paper were all taken at the lower frequency. To estimate the electron micropulse duration, the optical transition radiation induced by the electron micropulse was measured with a streak camera. The train of micropulses continues for 24μs (macropulse) and repeats at 20Hz. The usual FEL micropulse duration is determined by the detuning effect of the optical cavity and is shorter than half of the electron micropulse duration (bunch length) of several picosecond. The detuning effect on visible-and ultraviolet-FEL micropulse duration was measured with the streak camera. The FEL micropulse duration varies from 2.7ps to 0.9ps according to the detuning.[19]

The FEL peak and average powers of FEL-1 are 6MW and 0.2W at 7.5μm, respectively, at the outlet of Au-coated front mirror with 1-mm aperture. The FEL peak power of FEL-2 is 2MW at 1.88μm at the 0.5-mm aperture of Au-coated mirror and those of FEL-3 are 1.8MW at 0.35μm and 4.7MW at 0.6μm at the multilayer mirror. Fig. 4 shows the average FEL powers measured at each front mirrors as a function of wavelength.

Experimental data on the wavelength dependence of $\Delta\lambda/\lambda$ agree with the estimated valules calculated from $\Delta\lambda/\lambda=(1/\pi)\sqrt{\lambda}R/N\sigma_z$, where N is the number of undulator periods and σ_z is the standard deviation of the electron bunch length.

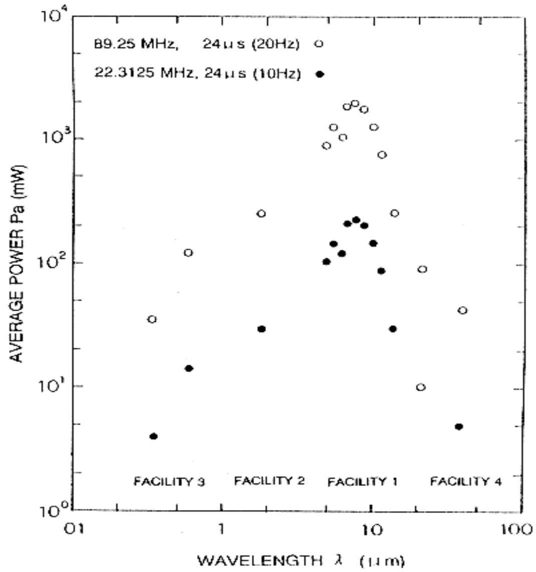

Fig. 4 Average powers vs wavelength

FEL BEAM SHARING FOR USER'S ROOMS

The FEL beams are delivered from the optical cavities to the diagnostics room and four user's rooms (eighteen stations) on the third floor through the optical pipes as shown in Fig. 5 [20]. Since Oct. 1995, FEL-1 was open for FEL users for two days a week. Since the end of Oct. 1996, FEL-1 and FEL-2 are open for users every other week. Total operation time in 1996 was about 2,400 hours.

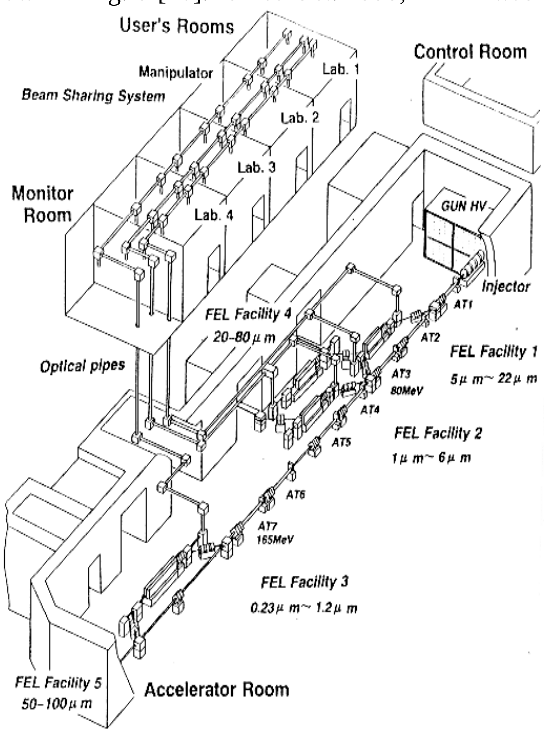

Fig. 5 Bird's eye view of FEL facilities and user's rooms of the FELI

The FEL beam extracted from the narrow aperture becomes thick and round due to diffraction and is delivered to the diagnostics room and four user's rooms. The FEL power and spectrum are always monitored with a fan-shaped mirror [21] at the diagnostic room and the linac control room.

The thick and round FEL beam is suitable for simultaneous FEL beam sharing to the diagnostics room and the user's stations, using fan-shaped Au-coated mirrors. The opening angle of the fan-shaped Au-coated mirror can change the sharing ratio of delivering FEL average power to the diagnostics room and the user's rooms. For the present FEL diagnosis, a quarter of the round FEL beam is shared using a fan-shaped mirror with a 90°-opening angle. Two manipulators were installed in Lab. 2. Each can focus the FEL beam to a 0.1-mmϕ MIR-FEL spot size inside of 3-m diameter working area.

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