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OPERATION OF LINAC BASED FELs IN IR- AND VISIBLE-RANGE AT THE FELI

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Abstract

Two infrared free electron lasers (FELs) facilities covering the wavelength range of 1-20 μm are opened for FEL users in this October. We are also challenging 0.3 μm-FEL oscillations using a 2.68m undulator (λ_u=4cm) installed at the 160-MeV beam line of the FELI linac with a thermionic gun. A 0.52-μm spontaneous radiation of 0.1W has been observed using a 145-MeV electron beam and the undulator.

INTRODUCTION

The Free Electron Laser Research Institute, Inc. (FELI) has been established in March 1991 and has achieved first lasings at infrared- and visible-range using an S-band 80-MeV electron linac with a thermionic gun driven by a 500-ps, 22.3125-MHz grid pulser in Oct. 31, 1994 and Feb. 28, 1995, respectively, in a year from the start of the machine installation [1]. At the FELI there are three free electron laser (FEL) facilities installed along by the beam line of an S-band 160-MeV linac, as shown in Fig. 1. The linac and these FEL facilities are located in the accelerator room on the ground floor.

The FEL beam becomes rather thick and round due to hole coupling and is delivered to the diagnostics room and eight user's stations on the third floor through the evacuated pipeline, and is further delivered through a simultaneous FEL beam sharing system [2] from the diagnostics room to eight user's stations.

The FELI 160-MeV linac, the S-type BT line 3 [3] and the FEL facility 3 (covering from 0.3 μm to 1.2 μm) are in the commissioning stage.

We are trying to achieve UV-range FEL oscillations using the FELI linac with the thermionic gun, taking the advantage of the thermionic gun's superior performances such as long-life, easy operation, and low-cost, in addition to some attempts on low emittance beam acceleration of the order of 10 π mm · mrad in the 6-MeV injector [4].

IR- AND VISIBLE-FELs AT THE FELI

First lasing at 5.5 μm was achieved using the FEL facility 1 composed of a 2-m long planar undulator (λ_u=3.4cm) [5] and a 6.72-m optical cavity [6] installed at the 30-MeV BT line of the FELI linac in Oct. 31, 1994. The FEL beam can be delivered from a 0.5-mm aperture in the upstream mirror of the optical cavity to the diagnostic room through a 50-m long evacuated pipeline as shown in Fig. 1.

First lasings at 1.88 μm and 0.63 μm was achieved using the FEL facility 2 composed of a 3-m long planar undulator (λ_u=3.8cm) and a 6.72-m optical cavity installed at the 80-MeV BT line of the FELI linac in Feb. 27 and 28, 1995. The FEL beam can be delivered from a 0.5-mm aperture in the upstream mirror of the optical cavity to the diagnostics room through a 40-m long evacuated pipeline.

The characteristics of the linac beams, the undulators used in these oscillations and lasing are shown in ref. [1].

Fig. 2 shows average FEL powers as a functin of wavelength at a 0.5-mm aperture in the upstream mirror of the optical cavity. A spectral range of the facility 1, between 5 and 22 μm, is covered using three electron energy values: 32, 26 and 20MeV. A spectral range of the facility 2, between 1 and 6 μm, is also covered using four electron energy values: 78, 62, 50 and 40MeV. The present maximum average power is

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0.14W at 7.5 μm at the 0.5-mm aperture in the upstream mirror of the FEL facility 1 for 4000 micropulses/s. The FEL micropulse duration is not measured yet but estimated to be 10 ps from the electron bunch measurement with a streak camera. The peak power is calculated from an average power, the micropulse duration and the number of micropulses in the FEL macropulses. The peak powers of the FEL facility 2 are about 2MW and 0.45MW at 1.88 μm and 0.63 μm, respectively, at the 0.5-mm aperture in the upstream mirror.

The peak power of the facility 1 reaches up to 70% of the theoretical limit $EI_p/(4eN)$, where E is the electron energy (MeV), I_p is peak current (A), e the electron charge, and N is the number of periods of the undulator. The present intracavity peak power is about 0.7GW at 7.5 μm. Therefore, the average power of 0.5W will be obtained by using the mirror aperture of 1mmϕ and should be 4W at a high micropulse repetition rate of 178.5MHz of the 500-ps grid pulser. Considering the fact that the electron beam diameter is 1mm and the optical beam waist is 2.5-5.4mm for the wavelength λ_{FEL}=4.8-22.7 μm, the peak power as well as the average power will be improved at wavelengths longer than 10 μm by changing the mirror curvature. Furthermore, both will be improved at these wavelengths by changing the aperture from 0.5mm to 1mm, since the transparency of FELs declines at these wavelengths.

On the other hand, a 2-MW peak power of the facility 2 is a seventh of the expected value but this is due to a small filling factor between the low emittance beam whose diameter is less than 0.5mm and a 1.5-mm waist of the stored FEL beam at 1.88 μm.

Red color beam were observed on the third harmonics at 1.88-μm oscillation and on the fifth harmonics at 3.1-μm oscillation.

CHALLENGE AT ULTRAVIOLET-RANGE FEL

The 160-MeV linac consists of the 6-MeV injector [4] and seven ETL type accelerating waveguides [7] as shown in Fig. 1. These accelerating waveguides are of linearly narrowed iris type to prevent beam blow up (BBU) effects at high peak current acceleration. The length of the linac including bending sections of two S-type BT systems for two IR-FEL facilities is 46m.

An rf system for linac based FELs requires rf sources with long pulse duration and high stability. Our rf sources are a klystron (1VA88R) for the 714-MHz prebuncher and two klystrons (E3729, 24MW for 24-μs flat top pulses per each) for the buncher and seven accelerating waveguides. The latter klystrons are modified for a 24-μs pulse operation [8]. A modulator for the klystron 1VA88R uses MOS-FET modules [9]. However, a modulator for the klystron E3729 consists 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 duration [10] . An rf-ageing for new four accelerating waveguides of the high energy section was started in June.

The FEL facility 3 including a 2.68-m undulator (λ_u=4.0cm, N=67, K_{max}=1.9, gap length$\geqq$18mm)[11] and an optical cavity (L_c=6.72m) was installed in July.

The optical cavity 3 is the Fabry-Perot cavity which consists of two mirror vacuum chambers. Each chamber has a rotating type mirror holder accommodating eight mirrors. One mirror position is empty and used for alignments of the optical cavity line and the five OTR beam profile monitors. The cavity mirror is controlled with a resolution of 0.1 μm or 10 μrad. To cover wide wavelength range from 0.3 μm to 1.2 μm, seven dielectric multilayer mirrors for IR-, visible-, and ultraviolet-range are installed.

A calculated small signal gain of this undulator is 7.8% per pass for a 0.3-μm spontaneous radiation using a 160-MeV, 50-A electron beam when the K parameter is 0.95 [12,13]. The net gain is estimated to be larger than 7.3%, considering that an extraction factor of a dielectric multilayer mirror is 0.4% and the mirror loss per roundtrip of the spontaneous radiation is 0.1%. Figure 3 shows a 0.52-μm spontaneous macropulse shape measured with a Si-photodetector (Si-APD C5331-04, HAMAMATSU PHOTONICS Inc.) and an electron current pulse measured with a button monitor [14]. The peak power of the spontaneous radiation is about 0.1W on August 18, 1995.

CONCLUSIONS

IR- and visible-range FELs are delivered to the diagnostic room and eight user's stations through the evacuated pipelines and simultaneous beam sharing systems. The FELI 160-MeV linac and the FEL facility 3 including the 2.68-m undulator and the 6.72-m optical cavity are in the commissioning stage.

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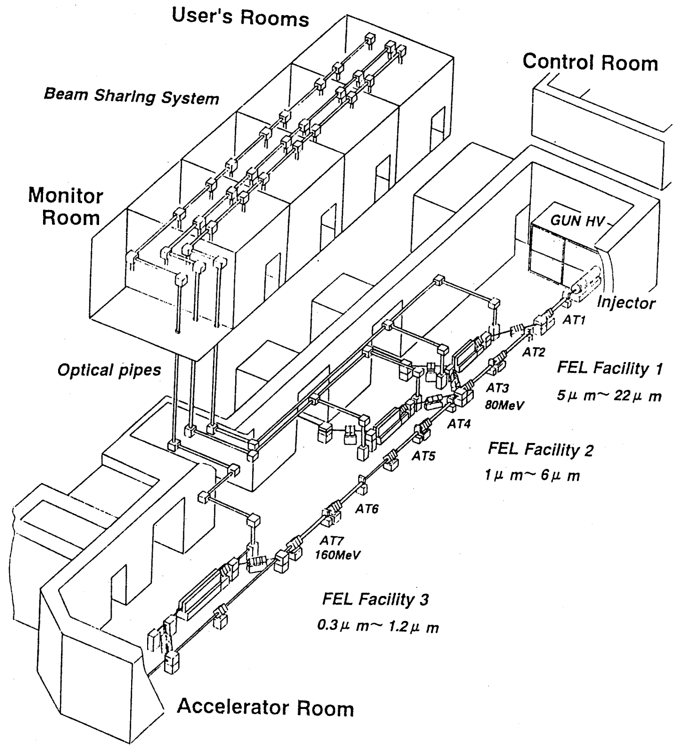

Fig. 1 Bird's eye view of three FEL facilities at the FELI

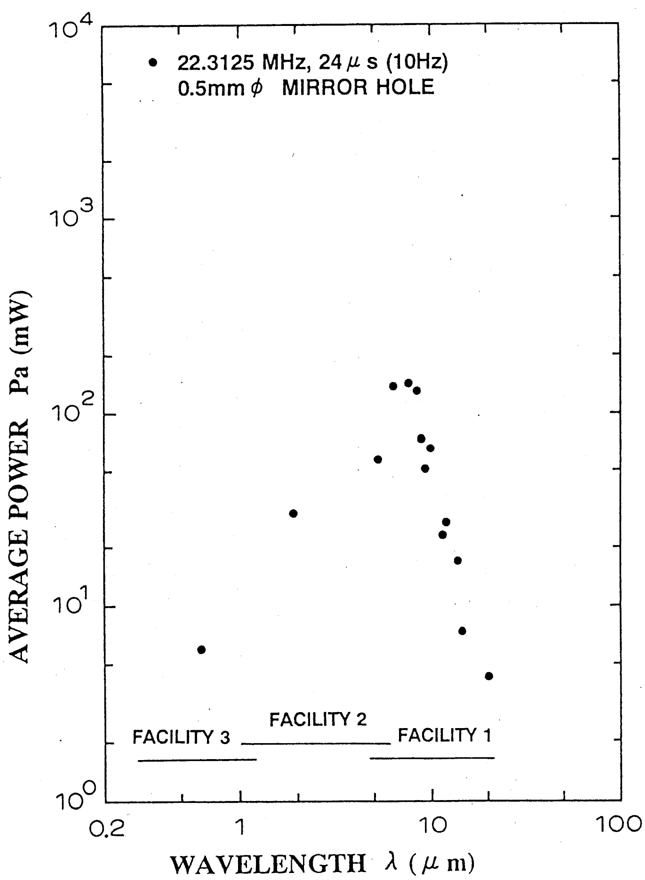

Fig. 2 Average FEL powers as a function of wavelength

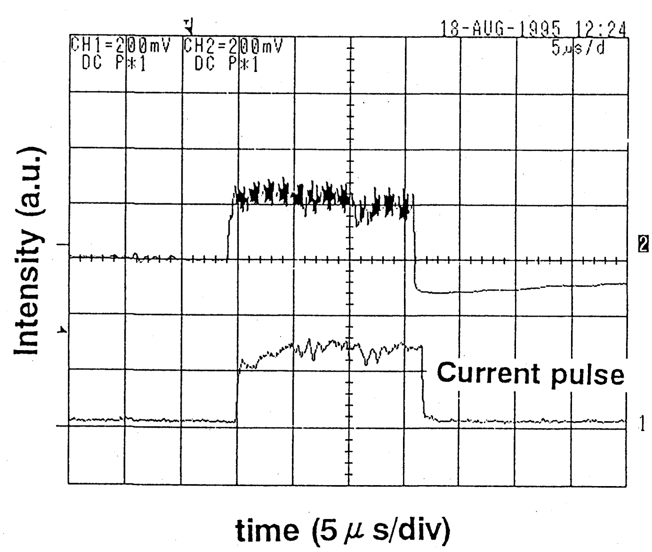

Fig. 3 0.52-μm spontaneous macropulse and current pulse