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FEL User's Facilities for Application Researches at the FELI

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Abstract

Two electron linacs and five FEL facilities were designed and constructed at the FELI from FY1993 to FY1995. Three FEL Facilities 1, 2 and 3 achieved lasings in Oct. 1994, in Feb. and in Dec. 1995, respectively. The FEL Facility 3 has broken a world record for the shortest wavelength oscillation using a linac with a thermionic gun up to 0.278 μm on June 6, 1996. FEL Facilities 4 and 5 were designed and constructed in 1995 to extend FEL applications to semiconductor devices at far–infrared wavelengths. Facilities 4 and 5 are in the commissioning stage.

The FEL Facility 1 covering the wavelength from 4.8 to 20 μm is opened for the FEL users for two days of a week. Basic studies on MIR–FEL applications are carried out in four user's rooms. Main subjects are DNAs and material introduction into the stem cell, ablation of dental substance, annealing of SiC, band discontinuity measurement of heterojunctions, optical modulation in semiconductor quantum wells and isotope separation of carbon and silicon.

The Free Electron Laser Research Institute, Inc. (FELI) was established in March 1991. A building (floor space 4,013m^2) used for developments of FEL facilities and FEL applications was designed and constructed in Tsuda Science Hills, Hirakata City in November 1993.

The main facility consists of an S-band, 165–MeV electron linac with a thermionic gun, beam transport (BT) lines and four FEL Facilities 1, 2, 3 and 4 as shown in Fig. 1. A compact facility composed of a 20–MeV linac with an RF–gun and FEL Facility 5 is also shown in Fig. 1. Each FEL Facility consists of an undulator, an optical cavity and an optical pipeline. FEL Facilities 1, 2 and 3 were designed in 1993 and 1994 to cover the wavelengths from 0.23 μm to 22 μm of our appointed research target. However, FEL Facilities 4 and 5 were designed in 1995 to extend our FEL applications to semiconductor devices at far–infrared wavelengths from 20 μm to 100 μm.

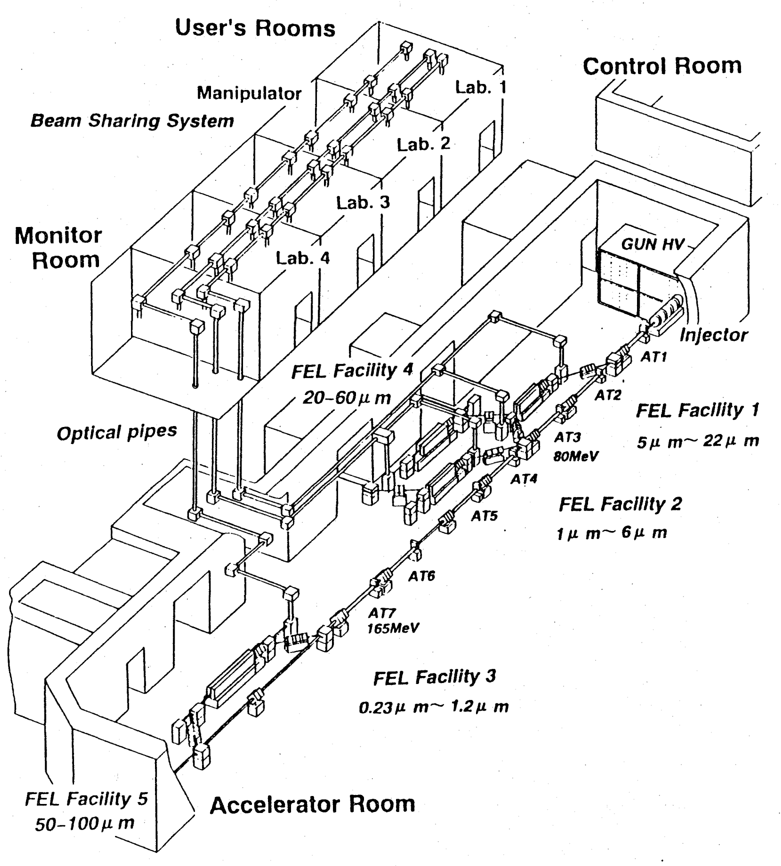

Fig. 1 Bird's eye view of FEL Facilities, user's rooms and beam transport system at the FELI

The spontaneous radiation and FEL beam from the main facility are delivered from the optical cavity on the first floor to the diagnostic room on the third floor with six Al-coated mirrors. Their macropulse shape, macropulse power and spectrum are measured simultaneously there.

Their installations were begun in January 1994 and finished in March 1996. The main one was installed in the accelerator room, the klystron room and the FEL user's rooms, and the compact one was installed in the laser instrument room .

The FEL oscillation experiment was begun at the Facility 1 (5–22 μm) in August and succeeded in lasings at 5–7 μm in October 1994 [1]. The Facilities 2 (1–6 μm) and 3 (0.23–1.2 μm) achieved lasings at 1.88–3.1 μm in February [2] and at 0.339–0.353 μm and in December 1995, respectively [3].

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 the Facility 3 has broken a world record for the shortest wavelength oscillation up to 0.278 μm as of June 6, 1996.

The FEL beams are delivered from the optical cavities to the diagnostics room and four user's rooms through the optical pipes as shown in Fig. 1. Since October 1995, the FEL Facility 1 is opened for FEL users for two days of a week. Three days of a week are used to grade up the Facilities 2 and 3 and to achieve lasings at the Facilities 4 and 5 in far-infrared range.

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

In order to increase the average FEL power, we are trying to increase the present 22.3125MHz repetition rate of the micropulse up to 89.25MHz and the repetition rate of the macropulse up to 20Hz. Another attempt is to use a cavity mirror with a larger aperture, for instance, a cavity mirror with a 2.0-mm ϕ aperture for the FEL Facility 1 and a cavity with a 1.0-mm ϕ aperture for the FEL Facility 2. Although this procedure reduces a net FEL gain and an FEL macropulse duration, the average FEL power will increase. These improvements are expected to increase average powers up to several W.

The wavelength dependence of FEL spectral width $\Delta\lambda$ is also an important parameter, especially in Si isotope separation by multiphoton decomposition process.
Experimental data on the wavelength dependence of $\Delta\lambda/\lambda$ are plotted in Fig 2 [4].

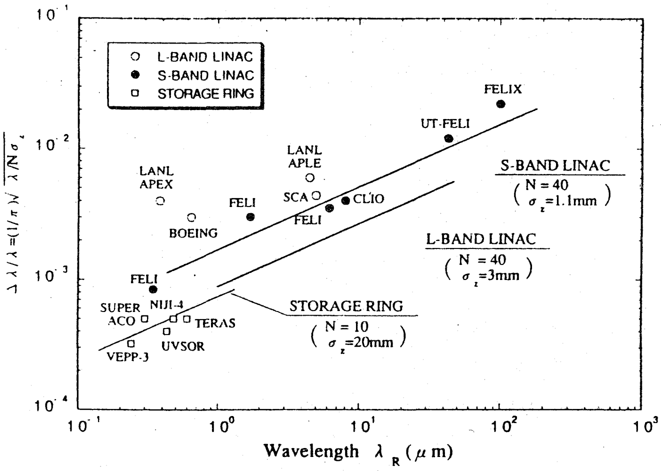

Fig. 2 Relations between spectral width and wavelength

The FEL beam extracted from the narrow aperture becomes thick and round due to hole coupling and is delivered to the diagnostics room and four user's rooms on the third floor through the optical pipelines as shown in Fig. 3. The FEL power and spectrum are always monitored with a fan-shaped mirror at the diagnostic room.

Two manipulators were installed in Lab. 2. Each can focus the FEL beam to a 0.1-mm ϕ sopt of MIR-FEL beam inside of 2-m diameter.

Basic studies on IR-FEL applications carried out in four user's rooms are as follows.

(1) DNAs introduction into the stem cell from which all blood cells are derived (in Lab. 1) [5].
(2) Ablation and annealing of dental hard substances (in Lab. 2) [6].
(3) Material introduction into cultured T lymphocytes (in Lab. 2) [7].
(4) Band discontinuity measurement of ZnSe/GaAs heterojunction (in Lab. 3) [8].
(5) Ultrafast all-optical modulation in semiconductor quantum wells (in Lab. 3) [9].
(6) Isotope separation of carbon and silicon by multiphoton decomposition process (in Lab. 3) [10].
(7) Annealing of silicon carbide and amorphous silicon (in Lab. 4) [11].

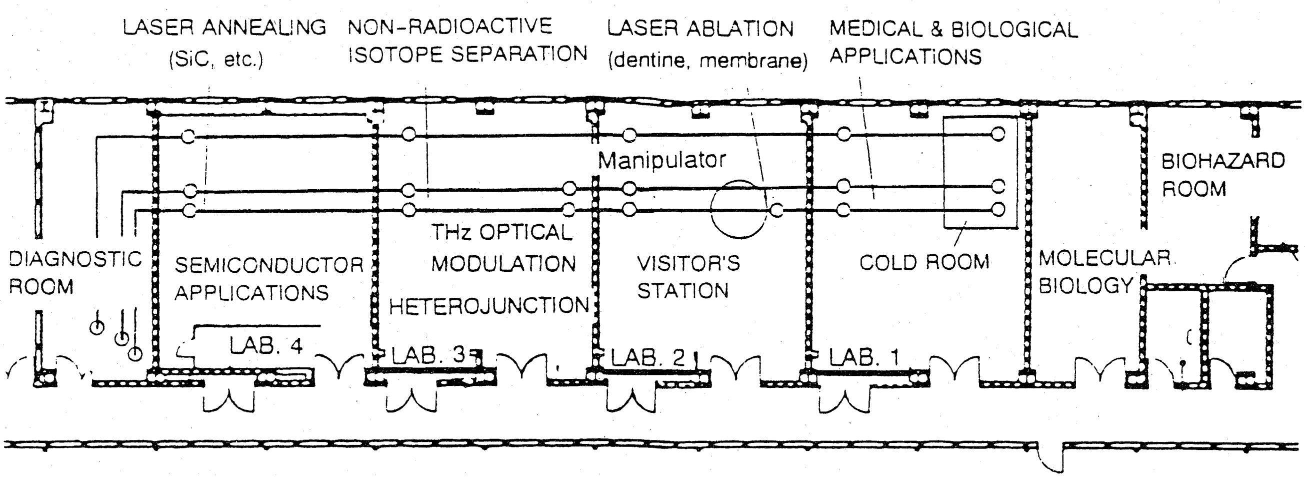

Fig. 3 FEL user's facilities at the FELI

The FEL Facility 4 (20–60 μm) including a 2.7-m long hybrid type undulator with electro- and permanent-magnets (λ_u=9cm, N=30) and a 6.72-m long optical cavity was installed at the 33-MeV beam line of the downstream of the FEL Facility 1 in March 1996. An FEL beam is delivered from the downstream optical cavity to the user's rooms through the pipeline of the Facility 2. Since the middle of June, we are trying to pass a well collimated beam through the undulator 4 [12].

The FEL Facility 5 (50–100 μm) of the compact facility, including a 2.24-m long undulator (λ_u=8cm, N=28) and a 5.04-m long optical cavity, was installed at the 20-MeV beam line of the 20-MeV linac with an RF-gun in the laser instrument room in March 1996. An FEL beam is delivered from the upstream optical cavity to the laser experimental room through the pipeline. The operation of compact facility including final RF ageing was begun in May and the beam acceleration was started in the middle of June for the legal inspection of our radiation protection system.

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