FREE ELECTRON LASER PROJECTS AT KAERI

B.C. Lee, Y.U. Jeong, S.O Cho, S.H. Park
Korea Atomic Energy Research Institute (KAERI),
P.O. Box 105, Yusong, Taejon, 305-600, . Korea

Abstract

KAERI has developed three types of free electron lasers (FELs) since 1992: a millimeter-wave (MMW) FEL driven by a 0.4-MeV electrostatic accelerator, a compact far-infrared (FIR) FEL driven by a 7-MeV microtron, and an infrared FEL with average power of ~ 1kW driven by a 40-MeV supersonducting accelerator. Successful lasing of the MMW FEL and the compact FIR FEL were demonstrated in 1994 and 1999, respectively. A 2-MeV injector for the infrared FEL has been completed, and the main superconducting accelerator section is being constructed.

1. INTRODUCTION

Free electron laser is a device generating wavelength-tunable high-power laser beams by extracting energies from relativistic electron beams. A FEL system consists of three parts; an electron accelerator for accelerating electrons to the speed of light, an undulator for making undulatory motions of electron to convert electron's kinetic energy into the electromagnetic energy, and an optical resonator for confining the radiation to amplify the coherent light beams.

Tunable high-power FELs with an excellent beam quality promise great deal of utilities in various fields such as basic science researches, medical applications, life sciences, environmental industries, nuclear industries, defence industries, semiconductor processing, polymer processing, etc.. Since the FEL can provide new wavelengths not available from the conventional laser devices, utilities of those wavelengths will open new application areas of light.

2. MILLIMETER-WAVE FEL

Figure 1 shows a photograph of the millimeter-wave FEL and Table 1 shows the parameters of the FEL. The MMW FEL is driven by a 400-keV electrostatic accelerator, and its wavelength is tunable over 3~10 mm. The MMW FEL consists of a 30 keV electron gun, a 400 keV electrostatic acceleration column, a permanent-magnet helical undulator, a deceleration column, and a collector. After passing through the undulator, the ‘spent’ electron beam is decelerated and captured by the collector. Due to this “beam recovery” structure, the efficiency of the system is as high as 60%. A compact permanent-magnet helical undulator was developed for the MMW FEL[1-4].

Table 1 : Parameters of the KAERI MMW FEL

Electron Beam	Energy	430 keV
	Current	2 A
	Emittance	20 π mm·mrad
	Pulsewidth	30 μs
Undulator	Type	Helical, PM
	Period	33 mm
	No. of periods	28
	Magnetic field	1.33 kG
Laser Beam	Wavelength	3~10 mm
	Mode	TM_{11}
	Power	1 kW

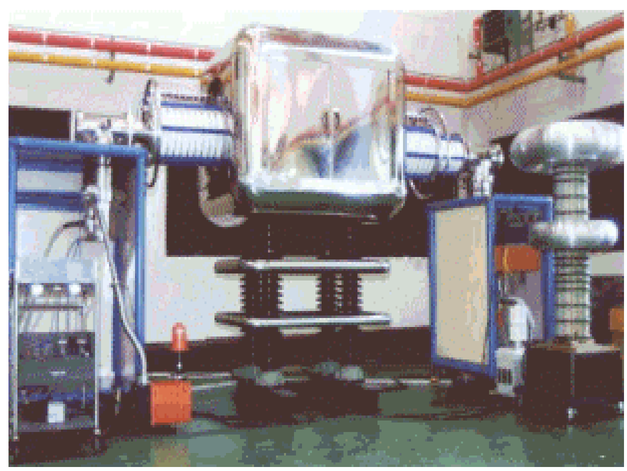

Figure 1: Photograph of the millimeter-wave FEL

3. BROAD-BAND FIR FEL

From 1996, KAERI has developed a compact far-infrared FEL based on a 7-MeV magnetron-driven microtron accelerator[5-10]. Figure 2 shows a photograph of the FIR FEL and Table 2 shows the parameters. The microtrons is very compact (70 cm in diameter) and has a simple acceleration structure. The quality of the electron beam is good enough to guarantee high FEL : the energy spread (ΔE) and the transverse emittance (ε_y) of the electron beam are 0.3%, and 1 mm-mrad, respectively. The use of a compact low-cost magnetron (instead of an expensive Klystron), makes the accelerator cheap, compact, and simple. A special technology has been developed for the stabilization of the frequency of the magnetron. A high-performance permanent-magnet-assisted electromagnet undulator has been developed for the FIR FEL. The magnetic field strength of the undulator is higher by 10 % than that of pure permanent-magnet undulator, and its r.m.s distribution error is as small as 0.05%, which enable high FEL gain and perfect transport of electron beam through the undulator. First lasing of the FIR FEL was achieved at the end of 1999, and now the FEL is operating stably in the wavelength range of 100-150 μm. The wavelength range will be extended to 90-300 μm. by extending the energy tenability of the electron beam.

Table 2 : Parameters of the KAERI far-infrared FEL

Electron Beam	Energy	6.5-7 MeV
	Current	40 mA (macropulse)
		1 A (micropulse)
	Energy spread	0.3 %
	Repetition rate	0.6~10 Hz (macropulse)
		2.8 GHz (micropulse)
	Pulsewidth	5.5 μs (macropulse)
		30 ps (micropulse)
Undulator	Type	Hybrid
	Period	25 mm
	# of periods	80
	Magnetic field	4.8~6.8 kG
Laser Beam	Wavelength	100-150 μm (present)
		90-300 μm (upgrade)
	Linewidth	0.3 %
	Power	100 W (micropulse)

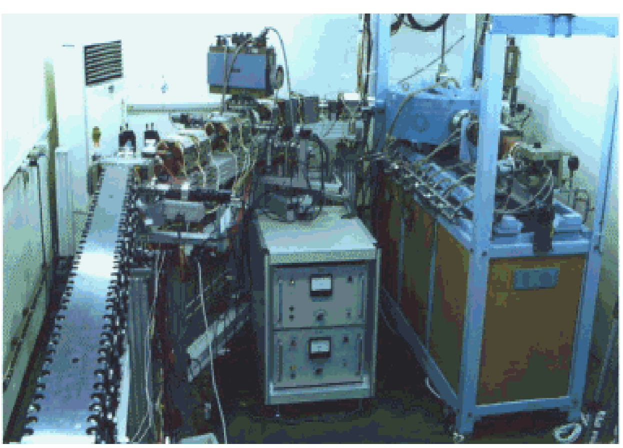

Figure 2 : Photograph of the KAERI FIR FEL

4. HIGH-POWER IR FEL

A schematic of the high average power infrared FEL is shown in Figure 3, and the parameters of the FEL is shown in Table 3. The FEL system is composed of a 2-MeV injector, a ~40-MeV superconducting acceleration section, one recirculation beamlines, an undulator, a pair of optical cavity mirrors, and an e-beam dump. The 2-MeV injector has already been completed, and the superconducting acceleration section is being constructed. The recirculation beamline and the undulator is being designed.

The 2 MeV injector consists of a 300-keV electron gun, a RF bunching cavity and two 0.8-MeV RF acceleration [11-12]. The average current of the electron beam is as high as 10 mA. The main accelerator is composed of two 352-MHz superconducting radio frequency (RF) accelerator modules, each of which gives acceleration gain of ~20 MeV. Each of the SC acceleration modules is composed of two four-cell RF cavities, and is fed by two 50-kW tetrode-type RF generators.

Table 3: Parameters of the high power infrared FEL

Electron Beam	Energy	20-40 MeV
	Average Current	10 mA
	RF Frequency	352 MHz
	Injection Energy	2 MeV
Undulator	Type	Hybrid, Optical Klystron
	Period	35 mm
	No. of periods	30 x 2
	Magnetic field	1.7-3.3 kG
Laser Beam	Wavelength	3~20 μm
	Average Power	1-5 kW
	Pulsewidth	~20 ps
	Repetition rate	22 MHz max.

In the design of the recirculation beamline of the high power IR FEL, the concept of energy recovery is very important. The electrons from the injector get an energy of ~40 MeV at the RF cavities, and come to the FEL undulator magnetic system, where they loose their energy to the radiation. The "used" electrons return to the RF cavities in decelerating phase of the RF voltage and their energy is converted into RF energy. The electrons, having energy practically equal to the injection energy, are then directed to the beam dump.

Since the energy of the electron beam is converted into the energy of RF electromagnetic wave, it is not necessary to feed high power RF electromagnetic wave into the RF cavities in order to accelerate the electron beam. Only a small power of RF is needed in order to excite the accelerating field in the cavity, and therefore, the efficiency of the FEL system can become high. The IR FEL will generate ~20-ps pulses of radiation at a maximal repetition rate of 22 MHz with average power of 1~5 kW in the spectral range of 3-20 μm.

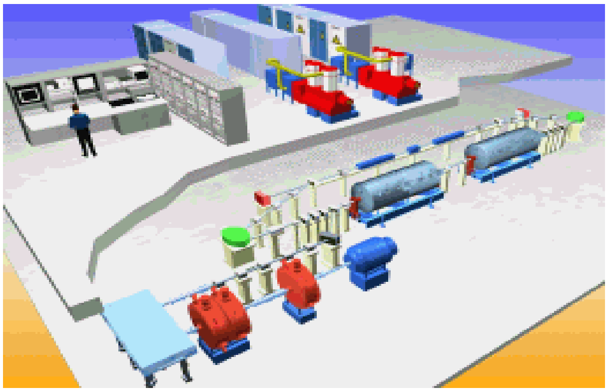

Figure 3: Schematic of the high power infrared FEL

5. APPLICATIONS OF THE FELS

A possible use of the millimeter-wave FEL is study of heating mechanism of plasma in a nuclear fusion reactor by using the mechanism of electron cyclotron resonance heating. It is possible to tune the wavelength of the millimeter-wave at the cyclotron resonance wavelength depending of the external magnetic field confining the plasma.

The compact FIR FEL will be used for various researches such as, rotational spectroscopy of molecules, investigation of quantum devices, surface physics, development of non-destructive testing system, and so on.

Due to high level of average power of the IR FEL, many industrial and scientific applications are promising. The wide-band IR FEL will enable users to research more precise spectroscopic studies of molecules, atoms, and solid-state materials. Those photon beams will open a new opportunity in bio-medical researches, where the characteristic response of molecules and radicals to long-wavelength radiation is important, and in solid state physics, where the energy of IR photons corresponds to the characteristic excitation levels of semiconductor quantum-structures. A wide tuning range of wavelength and narrow spectral width will enable the study of multi-photon dissociation process of molecules.

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