STATUS OF INSTITUTE OF FREE ELECTRON LASER, OSAKA UNIVERSITY

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Abstract

Institute of Free Electron Laser at Osaka University is FEL research facility, where beam physics and light application studies are being carried out. Owing to huge research field and to scientists or students of the university, various scientific studies have been initiated under collaborations with schools and institutes in the university, national institutes and industrial companies. The main research field in the institute concerns beam physics towards high quality longer wave length, semiconductor application, environmental chemistry and bio-medical applications, which are supported by the beam quality assurance of the beam physics study.

INTRODUCTION

Since the establishment in April 2000, Institute of Free Electron Laser Osaka university (iFEL) [1] has supplied the laser beam for about 5000 hours as well as the beam study. While the first year was spent for the test run of the accelerator, beam operation time reaches 1500-2000 hours per year afterwards. The research field mainly lies in Bio-Medical application, semiconductor research and Photo-chemistry, where 60%, 24% and 8% of the total machine time were dedicated, respectively. These application studies were carried out within collaborations with research groups in universities, national laboratories and industries. Many users in the research programs used the far-infrared radiation in the wavelength range from 5 to 20 μm, and requested for the longer wavelength up to 100 μm. Therefore the physics research aims to stabilize the infrared FEL system and extend the wavelength region towards longer wavelengths.

In this paper, we will present the achievements and the future plan of our institute. The accelerators and FEL systems will be described in the next section, and then the status of the application programs will be reported in the following section. The future plan will be also presented.

FEL SYSTEMS

Two S-band (2.856GHz) linear-accelerators are housed at iFEL. One has a maximum energy of 180 MeV, and the other an energy of 20 MeV. With these accelerator, the FEL system covers the wavelength range from 0.28 to 60 μm. Details of the FEL systems are described in the followings.

Main Linac

The main linac consists of seven S-band standing-wave accelerating tubes and boosts the electron energy up to 180 MeV. The electron bunches are injected into the accelerator at a frequency of 22.3 MHz, 1/128 of the S-band frequency, from a thermionic electron gun driven by a grid pulser. A sub-harmonic buncher compresses the electron beam of 500 ps into a 10 ps bunch to increase the peak current before injection into the accelerating sections. The 24 μs-long macropulse contains 550 electron bunches. The charge of single bunch is 0.25 nC. This macropulse is produced at a repetition rate of 10 Hz, and the corresponding average current is 2 μA. A small fraction of the charge, 5%, is lost as the bunch passes through the sections. The peak current is about 80 A at the 180 MeV beam line.

Three wigglers are installed on this linac and cover the ultraviolet to mid-infrared part of the spectrum, 0.28 - 20 μm. The MIR wiggler is fed by 25 MeV electrons and lases in the range of 5 - 20 μm, the NIR wiggler 80 MeV and 1 - 6 μm, the UVV (ultraviolet-visible) wiggler 180 MeV and 0.28 - 1.3 μm. The wiggler periods of MIR, NIR and UVV are 3.4, 3.8 and 4.0 cm, respectively. Almost the same period, but they are driven by different energy electron. The FIR system is installed to cover the wavelength range from 20 – 60 μm and is now under development. The wiggler has a 9 cm period and is fed by 25 MeV electrons which have passed through the MIR wiggler. We are aiming for the simultaneous operation of MIR and FIR systems to deliver “two color FEL beams”.

All the resonators have a length of 6.72 m so that one radiation micropulse is restored in them. A coupling hole (1.5 mm in diameter) is bored on the center of the Au-coated metallic mirror installed on the upstream side. The FEL light passes through this hole and is then converted into the parallel beam with a diameter of 200 mm in order to reduce the diffraction loss in the 50 m long transport to the user's room. The transport tubes for MIR and NIR are evacuated to reduce the absorption loss by air.

Figure 1 shows the average power vs. wavelength on the MIR system. The MIR system covers the 5-20 μm range with an average power of 20-45 mW. The power falls off in the vicinity of 6.1 mm probably because of absorption by residual water in the transport tube. The decrease in power for the longer wavelength range is due to electron transport loss in the accelerator and magnetic chicane. In the case of 17 μm operation, the average current drops to 1.7 μA. The wavelength is changed in two ways: the strength of wiggler field and the electron beam energy. The wiggler parameter, or the K-parameter, ranges from 1.0 to 1.5 with a gap spacing from 25 to 17 mm, respectively. (Although the wiggler itself can vary the K-parameter from 0.5 to 1.5, the FEL power is too small with K less than unity.) The tuning range by

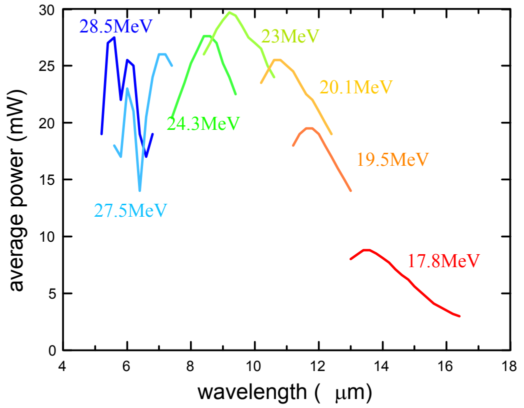

Figure 1. Tunabilty of the iFEL mid-infrared FEL system.

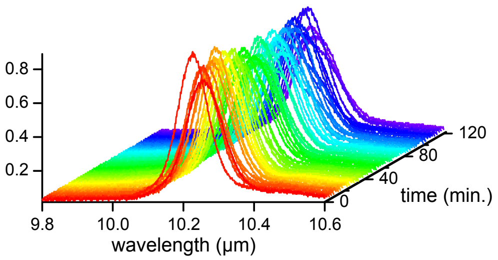

Figure 2. Spectral stability of the iFEL mid-infrared FEL system.

varying the K-parameter is then about 20%, for example, the wavelength can be varied from 8 to 10 mm with a fixed electron energy. In this way, the wavelength can be continuously varied in a minute.

For wider scanning, the electron energy is changed. The electron energy is varied by changing the rf-power to the accelerator. The energy is varied from 22 MeV to 26 MeV to cover the 5 - 20 µm range. Once the electron energy is changed, it takes about 10 minutes to adjust the accelerator components such as bending magnets, quadrupole lenses, phasing of the rf field, and so on.

The spectral width is varied by 0.8-1.6% according to the wavelength: for longer wavelength, the spectral purity tends to degrade. This ranges is limited by the device parameter (the number of wiggler periods is 58) and FEL physics (the spiking nature of the FEL micropulse).

For stable operation of the FEL, temperature control of the accelerator is the critical issue. The accelerator is cooled by water, which is controlled at a temperature of 40 degree centigrade with an accuracy of 0.1 degree. With this technique, we achieve long-period (-2-3 hours) stable operation. Figure 2 shows the spectral stability. The central wavelength fluctuates only 0.1 % during 2 hour long operation. This fluctuation is much smaller than the spectral width and does not make any practical problem so far. On the other hand, the average power stability is 1.9 %. Most of application programs call for better stability in the power. We are investigating the origin of the power fluctuation [2] and developing a more stable machine.

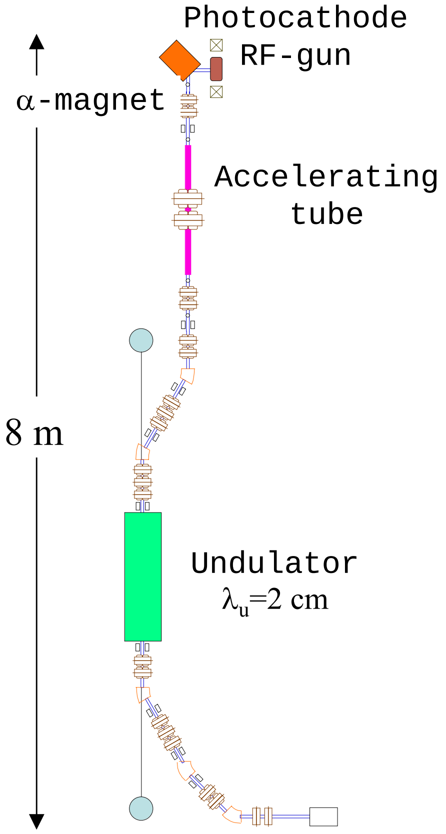

Figure 3. Compact FEL system for Bio-medical application programs

Compact FEL system for Bio research

In order to meet the growing request on the beam time, we are developing new far-infrared, 5-10 µm,FEL system fed by a compact 20 MeV accelerator. This system can be operated independently of the main accelerator and aims to drive the mass spectrometer for the Bio-Medical application programs. The accelerator consists of an RF-gun, the alpha-magnet and an accelerating tube. With a LaB6 thermionic cathode, the accelerator outputs an electron beam with a peak current of 10 A and pulse width of 3 ps during 5 µs macropulse-duration. This accelerator can also be operated as the photo-injector by irradiating the LaB6 cathode with a frequency-tripled mode-locked YLF laser running at 89.25 MHz which corresponds to 1/32 of the S-band RF frequency. In this case, the peak current reaches 60 A.

A hybrid planar undulator with a period of 2 cm and 50 total periods is installed in the magnetic chicane. With a gap spacing of 1 cm, the undulator achieves a K value of 0.5. The resonator consists of a pair of Au-coated mirrors with a spacing of 5.7 m. We expect 500kW peak power FEL output of and 20 mW average power.

For this FEL system, the pulse-picking system is developed to investigate the dynamics of photo-ionization and photo-dissociation. Also it is possible to use the mode-locked laser synchronized to the accelerator for the pump-probe experiments and MALDI experiment.

Research on the stability of FEL [2]

Figure 4 shows the detuning curve of the mid-infrared FEL system installed on the main linac and the time traces of the FEL macro pulse for various resonator lengths. It is seen that the stability of the FEL output is a function of the resonator. A detailed study has indicated that the power fluctuation was correlated with the fluctuation in the electron beam pulsewidth: the FEL power started to drop when the pulsewidth of the electron beam elongated while the power started to increase when the electron beam pulsewidth shortened. Numerical simulation reproduced these experimental result and revealed that the fluctuation in the FEL power arose from the non-linear evolution of the FEL micro pulse which was governed by the resonator length. The fluctuation in the electron beam pulse width has origin in the jitter between the grid pulse of the electron gun and rf of the sub-harmonic buncher. We are developing a feed back circuit to synchronize the grid pulse and the rf source of the sub-harmonic buncher.

Development of the light sources

In order to meet the resent growing interests of material science in the THz spectral range, we are developing a cyclotron laser [3]. This light source is installed on an 180 MeV beam-line of the main linac and produces radiation with a broadband continuous spectrum similar to the THz light source fed by femto-second laser. The peak power, however, is expected to be 1 MW, which is much more intense than the conventional light source in this spectral range. Also a millimeter range compact FEL using a micro-wiggler [4] and a tiny cherenkov FEL in the far-infrared range are under development. These small FEL systems are aiming at applications in practical situations.

Research in the photo-chemistry calls for a strong radiation source in the wavelength range from 2 μm to 4 μm. A near-infrared FEL system which can cover 1-5 μm is being developed using the 80 MeV beam-line of the main linac. For this wavelength range, we furnished a OPA light source fed by a femto-second Ti:Sapphire laser. This OPA system generates intense short-pulse light with a peak power of 1GW and a pulsewidth of 150 fs. Comparison of the response to FEL and OPA will be useful to study the nonlinear phenomena because of the large difference between the pulsewidth of these lasers.

APPLICATION PROGRAMS

So far, 40 application studies are performed within collaborations with research groups belonging to universities, national laboratories and private companies. The representative themes are listed in Table 1. Research

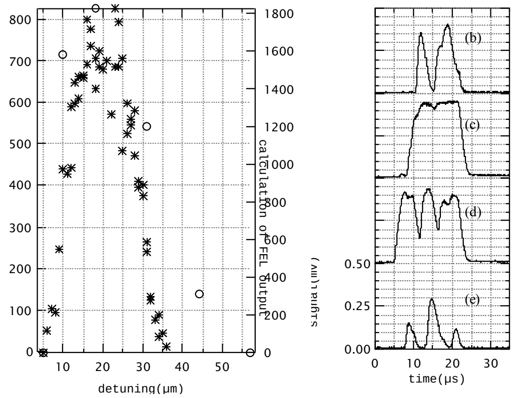

Figure 4. Detuning curve of the mid-infrared FEL system (a) and the time trace of the FEL macro pulse (b)-(e) φορ 9, 13, 26, ανδ 32 μm detuning, respectively.

Table 1. List of application programs

Theme	Collaborator
Semiconductor carrier dynamics under the mid-infrared radiation	Department of Electronics
Far-infrared absorption and photo-conduction of Semiconductors	Department of Physics
Ion-injection into the shallow junction formation using infrared FEL	Mitsubishi Electric Corporation, Ion Engineering Research Institute Corporation
Infrared sensor study	Mitsubishi Electric Corporation
THz semiconductor laser	Department of Physics
Thin-film deposition assisted by mid-infrared FEL	Osaka National Research Institute
Molecular ^{18}O concentration	Hitachi corporation
Domain Change of Columnar Liquid Crystal by FEL	National Institute of Advanced Industrial Science and Technology (AIST)
UV/FEL-MALDI mass spectroscopy for analysis of insoluble protein	the Intellectual Cluster Project
Photonic Intervention Processes for innovative Therapeutics	the Intellectual Cluster Project
Biomimetic lipped bilayers as matrix substances in MALDI-MS	National Institute of Advanced Industrial Science and Technology (AIST)
Infrared spectrographic distinguishing method for a phosphate group and the FEL irradiation effects against a phosphorylated peptide	Nara Institute of Science and Technology
Laser surgery in blood vessel for removal of cholesterol	School of Medicine
Modification of dental tissue by infrared lasers for caries therapy	Kinki university, Osaka dental university
Monitoring of soft tissue cutting using acoustic waves	Kansai university
Measurement of bio-regenerative material and modifications by FEL	Kyoto university

themes cover various fields: material science [5], chemistry [6], bio-medial research [7], and contain both fundamental and practical research.
Some of these programs of ^{18}O concentration, MALDI and semiconductor dynamics research, were proceeded with use of both the FEL and external lasers such as CO_2 laser, mode-locked YLF laser and N_2 laser. A synchronized OPA system which covers the 3-5 μm is operational.

FUTURE PLAN

The present operation project will be concluded at the end of March 2007. Beyond this period, a new project of application research that fully uses the present capability of the facility is being proposed. Development of medical applications is expected in the near future, including laser surgery and protein analysis with using the MALDI mass spectroscopy. Several years after 2007, it is hoped that advanced quantum semiconductors will be developed and widely used. These could not be performed or invented without using FEL grade lights, and such high quality light spectra can not be re-produced easily by conventional lasers.

The other application field of FELs would be in longer wave spectrum. So called radiation in terahertz region is difficult to be emitted by a conventional vacuum tube or by light crystals. Even though the accelerator based light source is large, it can generate much stronger radiation than existing sources. High quality light can be easily produced by FELs, and the present institute is strongly expected to supply light in this spectral range.

For the purpose of analysis, FEL stabilization is the key issue. Application projects that are based on steady physics research is the key issue of the institute, and our institute is expecting and welcomes innovative proposals of FEL itself and its application studies from all over the world.

CONCLUSION

Sine its establishment in 2000, iFEL Osaka university has supplied the FEL for 5000 hours during the operation period from 2001 to 2004. The users, belonging to the university, national laboratory and industrial company, utilized the facility for research in the various fields. Though the FEL system can potentially cover the spectral range from ultraviolet to fir-infrared, most of application programs were carried out with mid-infrared FEL system which can produce the mid-infrared from 5 to 18 μm. These programs call for the stability and the terahertz radiation. We are studying FEL physics and the accelerator physics for the stabilization. Proposals of the light source are also being developed to expand the wavelength range that our facility can deriver. The accelerator based radiation source is believed to be able to open a new scientific field in near future.

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