INFRA-RED FREE ELECTRON LASER AT TOKYO UNIVERSITY OF SCIENCE

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Abstract

IR-FEL research center of Tokyo University of Science (FEL-TUS) is a facility for aiming at the development of high performance FEL device and promotion of photo-science using it. The main part of FEL-TUS is a mid-infrared FEL (MIR-FEL) which consists of an S-band linac and an undulator combined with an optical resonance cavity. MIR-FEL provides continuously tunable radiation in the range of 5-14 μm and a variety of experiments by the use of this photon energy corresponding to the various vibrational modes of molecules are now underway. We also develop far-infrared FEL (FIR-FEL) installed an RF-gun with Disk-and-Washer accelerating cavity for high quality electron beam. We report the present status of FEL-TUS.

INTRODUCTION

The Infra-red free electron laser research center of Tokyo University of Science (FEL-TUS) was established in 1999 as a user facility dedicated for the application of infra-red free electron laser. The research project in the IR-FEL Research Center was financially supported by the Grant-in-Aid for the Creative Scientific Researches (Project No. 11NP0101) of Japan Society of Promotion Science (JSPS) from 1999 to 2003 fiscal year [1].

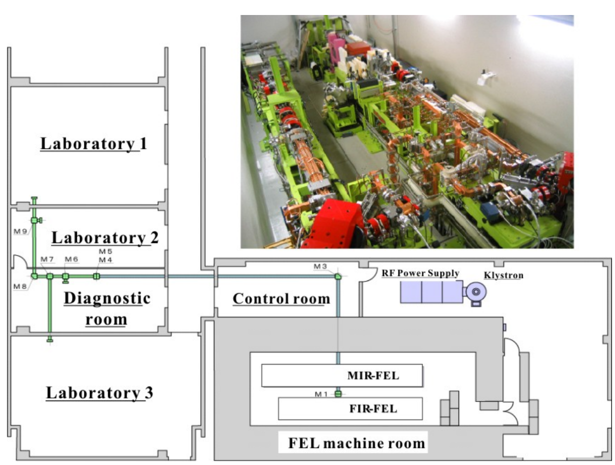

Figure 1: Layout of FEL-TUS. The facility includes a FEL machine room, a control room, a diagnostic room and three experimental rooms. The device on the right side is MIR-FEL and the one on the left side is FIR-FEL in the photograph.

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The main device of FEL-TUS is a mid-infrared FEL (MIR-FEL) which covers the wavelength region of 5-14 μm, which corresponds to the absorption frequencies for vibrational modes of molecules. The peak power of FEL is much higher than those of synchrotron light source and conventional light sources in this wavelength region. A variety of experiments utilizing special characteristics of MIR-FEL are now underway. Another FEL device is a far-infrared FEL (FIR-FEL), which is expected to cover the wavelength region of 300-1000 μm. We installed a newly developed RF-gun with Disk-and-Washer accelerating cavity as an electron source of FIR-FEL. The commissioning of FIR-FEL has been performed in the intervals of MIR-FEL user time due to the fact that simultaneous operation of two FEL devices is impossible because a common RF power supply is employed. Photograph of two FEL devices and the layout of FEL-TUS are shown in Fig. 1.

FEL-TUS is opened to researchers of not only Tokyo University of Science but also other universities, institutes and companies and has been supported by Open Advanced Research Facilities Initiative from the Ministry of Education, Culture, Sports, Science and Technology of Japan since 2007 fiscal year.

MIR-FEL

Fig. 2 shows a schematic layout of the MIR-FEL device which consists of an S-band linac and an undulator combined with an optical resonance cavity [2–7].

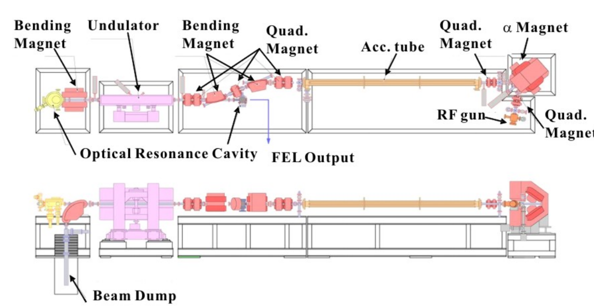

Figure 2: Schematic layout of MIR-FEL.

The injector part of MIR-FEL is a thermionic cathode RF-gun with on-axis coupled structure (OCS) [8–10] and an alpha magnet. The electron beam accelerated to a maximum 40 MeV by a 3 m long accelerating tube passes through two bending magnets and is transported to a Halbach-type undulator of 43 magnetic periods having the period length of 32 mm.

FEL output from a coupling hole of the optical resonator cavity is converted into a parallel beam in order to compensate its divergence. The conversion to the parallel beam is accomplished with a passive control optics consisted of an ellipsoidal mirror and a parabolic mirror in the FEL machine room [11]. The beam is then transported to the experimental area through the optics composed of several mirrors in vacuum tubes.

Fig. 3 shows the pulse time structure of FEL output. Each macropulse is about 2 μs long and consists of a string of micropulses at 350 ps intervals.

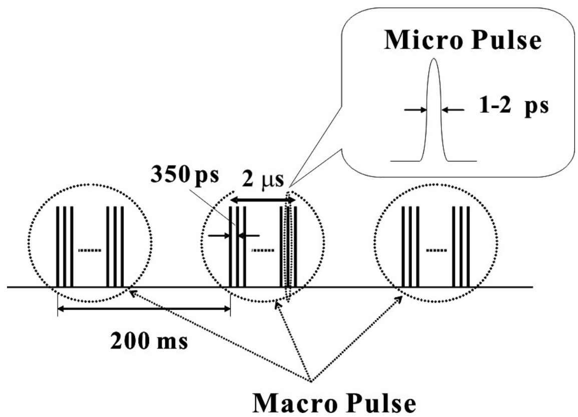

Figure 3: Pulse time structure of FEL output.

Application Experiments

The one of the main purpose of FEL-TUS is to promote photo science using IR-FEL. As already mentioned, MIR-FEL provides a powerful and wavelength-tunable laser pulse in the range of absorption frequencies for vibrational modes of molecules. Thus infra-red multiphoton dissociation (IRMPD) is supposed to be one of the primary research fields.

Typical experiments using MIR-FEL in recent years are as follows:

- Infra-red photodissociation spectroscopy of cluster ions [12–14].
- IRMPD spectroscopic analysis of peptides and oligosaccharides [15].
- Vibration excitation of polyatomic molecules in gas phase [16, 17].
- Isotope separation [18].
- Visible nonlinear band-edge luminescence in semiconductors [19].
- New reaction scheme on metal surface [20].

FIR-FEL

FIR-FEL, which is expected to cover the wavelength region of 300-1000 μm is an S-band linac based FEL similar to MIR-FEL as shown in Fig. 5 and the comparison of parameters of two FEL devices is listed in Table 1.

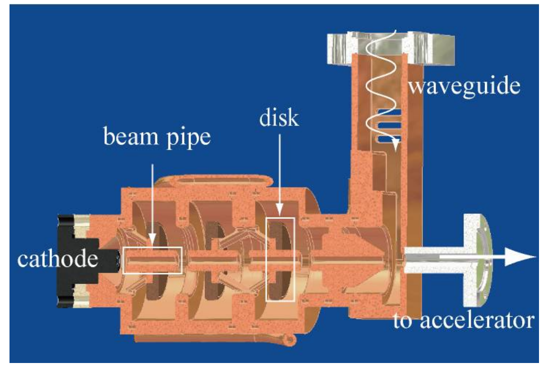

Figure 4: Schematic view of the RF-gun with DAW cavity.

Table 1: Comparison of parameters of FIR-FEL and MIR-FEL

	FIR-FEL (design)	**MIR-FEL**	
Wavelength	300-1000	5-14	μm
Electron beam energy	10	up to 40	MeV
Length of Acc. tube	1.5	3	m
Undulator			
Period	70	32	mm
No. of periods	25	43	
Optical Resonator Cavity			
Mirror	cylindrical		
Mirror curvature	2.0	2.0 (upstream)	m
		1.6 (downstream)	m
Mirror size	4.1×65	43 (diameter)	mm
Cavity length	2.5	3.36	m

The essential difference between the two FEL devices is the structure of optical resonator cavity. In the longer wavelength region, the large slippage effect occurs and leads to the FEL gain reduction. In order to suppress the reduction, a hybrid resonator which consists of a rectangular waveguide and cylindrical mirrors is adopted for the optical resonator cavity of FIR-FEL [21, 22].

RF-gun with DAW Cavity

A newly developed RF-gun with Disk-and-Washer (DAW) accelerating cavity was installed as an electron source of FIR-FEL. Adopting of DAW structure for the accelerating cavity leads to not only the simplification of the design and the fabrication of the cavity but high performance, such as the reduction of back-bombardment and the achievement of low emittance beam. Fig. 4 shows schematic view of the RF-gun with DAW cavity.

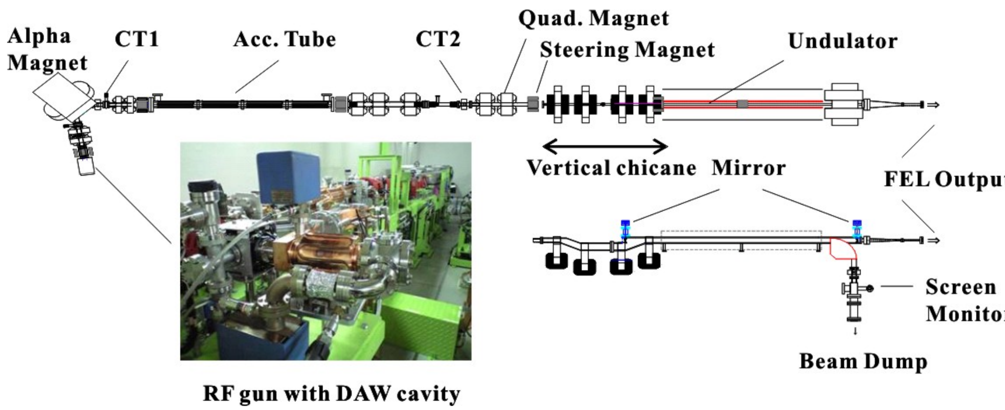

Figure 5: Schematic layout of FIR-FEL and photograph of a newly developed RF-gun with Disk-and-Washer accelerating cavity installed on the beamline.

Status of The Commissioning of FIR-FEL

The commissioning of FIR-FEL has been performed in the intervals of MIR-FEL user time. In the beam acceleration experiment conducted after the commissioning of the RF-gun, the beam transport to the beam dump and the detection spontaneous emission were successfully achieved as shown in Fig. 6 and Fig. 7, respectively.

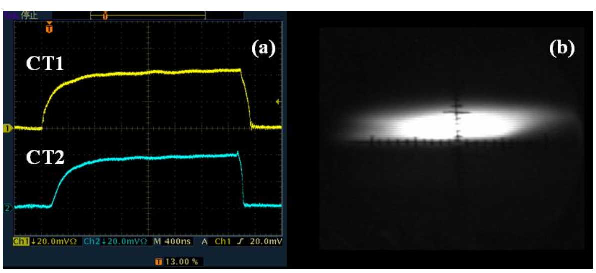

Figure 6: Beam current waveform measured by CT upstream (CT1) and downstream (CT2) of the accelerating tube (a) and beam spot on the screen monitor just upstream of the beam dump (b).

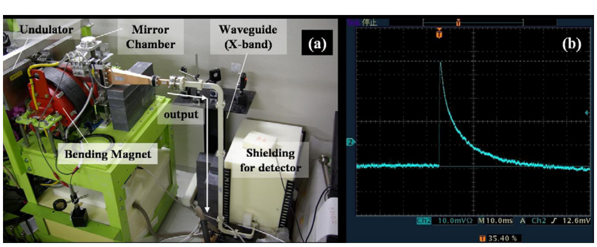

Figure 7: Setup of spontaneous emission measurement system (a) and signal from pyroelectric detector (b).

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REFERENCES

[1] H. Kuroda, Jpn. J. Appl. Phys. 41 (2002) Suppl. 41-1, 1.
[2] M. Yokoyama, et al., Nucl. Instr. and Meth. A429 (1999) 269.
[3] M. Yokoyama, et al., Nucl. Instr. and Meth. A475 (2001) 38.
[4] M. Yokoyama, et al., Nucl. Instr. and Meth. A483 (2002) 291.
[5] M. Yokoyama, et al., Nucl. Instr. and Meth. A507 (2003) 261.
[6] M. Yokoyama, et al., Jpn. J. Appl. Phys. 41 (2002) Suppl. 41-1, 49.
[7] F. Oda, et al., Jpn. J. Appl. Phys. 41 (2002) 414.
[8] F. Oda, et al., Nucl. Instr. and Meth. A429 (1999) 332.
[9] F. Oda, et al., Nucl. Instr. and Meth. A445 (2000) 404.
[10] F. Oda, et al., Nucl. Instr. and Meth. A475 (2001) 583.
[11] K. Nomaru, et al., Nucl. Instr. and Meth. A445 (2000) 379.
[12] K. Tono, et al., J. Chem. Phys. 129, 084304 (2008).
[13] K. Tono, et al., Chemical Physics Letters, 442, (2007) 206.
[14] K. Tono, et al., J. Chem. Phys. 125, 224305 (2006).
[15] K. Fukui, et al., J. Phys. Chem. B, Vol. 110, No. 32 (2006) 16111.
[16] Y. Ogi, et al., Chemical Physics Letters, 421, (2006) 96.
[17] Y. Ogi, et al., J. Electr. Spectrosc. Relat. Phenom., 128, (2003) 67.
[18] S. Gorelik, et al., Appl. Phys. Lett., Vol. 85, No. 19 (2004) 4529.
[19] E. Tokunaga, et al., Optical Review Vol. 17, No. 3 (2010) 1.
[20] M. G. Moula, et al., Bull. Chem. Soc. Jpn, Vol. 81, No. 7 (2008) 836.
[21] M. Sobajima, et al., Nucl. Instr. and Meth. A483 (2002) 240.
[22] H. Koike, et al., Nucl. Instr. and Meth. A507 (2003) 242.