STATUS OF IR-FEL 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 development of the high performance FEL device and promotion of photo-sciences using it. The main part of FEL-TUS involves a mid-infrared FEL (MIR-FEL) which 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 are also making effort to develop a far-infrared FEL (FIR-FEL) in order to realize FEL lasing in the THz region. This paper will describe the status of research activities at FEL-TUS.

INTRODUCTION

The Infra-red free electron laser research center of Tokyo University of Science (FEL-TUS) [1] was established in 1999 as a user facility dedicated for the application of infra-red free electron laser.

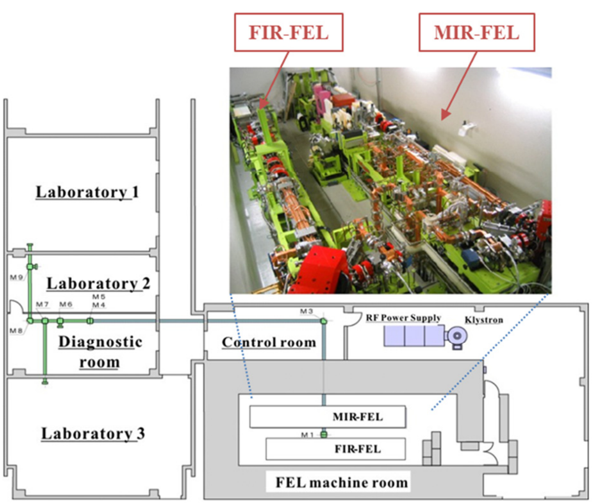

Figure 1: Layout of FEL-TUS.

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. 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. Figure 1 shows the top-view of the facility with a picture of two FEL devices.

FEL-TUS is open 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.

FEL DEVICE

Both MIR-FEL and FIR-FEL adopt a similar structure which consists of S-band linac with a thermionic cathode RF-gun and an alpha magnet, and an undulator combined with an optical resonance cavity.

The essential difference between the two FEL devices is the structure of optical resonator cavity. In the longer wavelength region, the large slippage effect may lead 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 FIR-FEL.

Figures 2 and 3 illustrate the schematic layout and photo of MIR-FEL and FIR-FEL, respectively. The comparison of parameters of two FEL devices is listed in Table 1.

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

	MIR-FEL	FIR-FEL	
Wavelength	5-14	300-1000	μm
e^- beam energy	40	10	MeV
RF Gun Cavity	On-axis coupled structure	Disk and Washer	
Length of Acc. tube	3	1.5	m
Undulator			
Period	32	70	
No. of periods	43	25	
Optical Resonator	Fabry-Perot	Hybrid*	
Mirror Size	43	4.1 x 65	mm
Cavity length	3.36	2.5	m
Status	User Operation	Commissioning in progress	

* a rectangular waveguide and cylindrical mirrors

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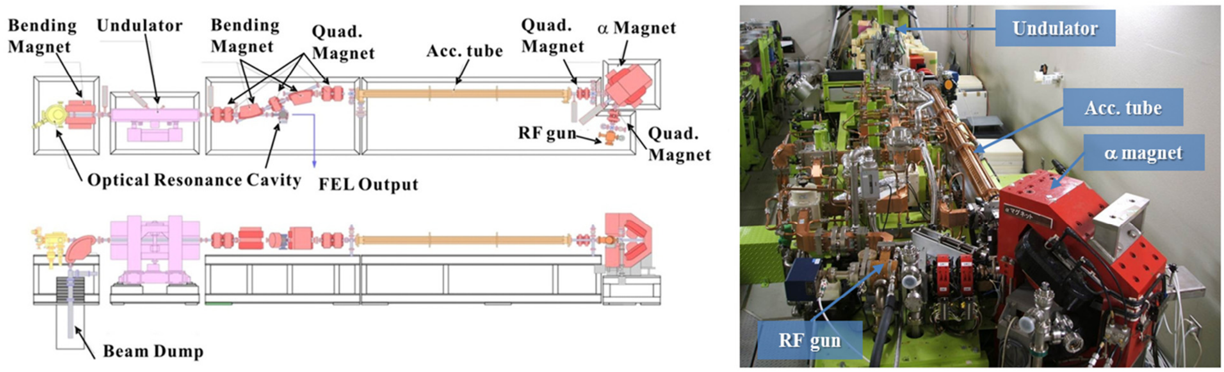

Figure 2: Schematic layout and Photograph of MIR-FEL.

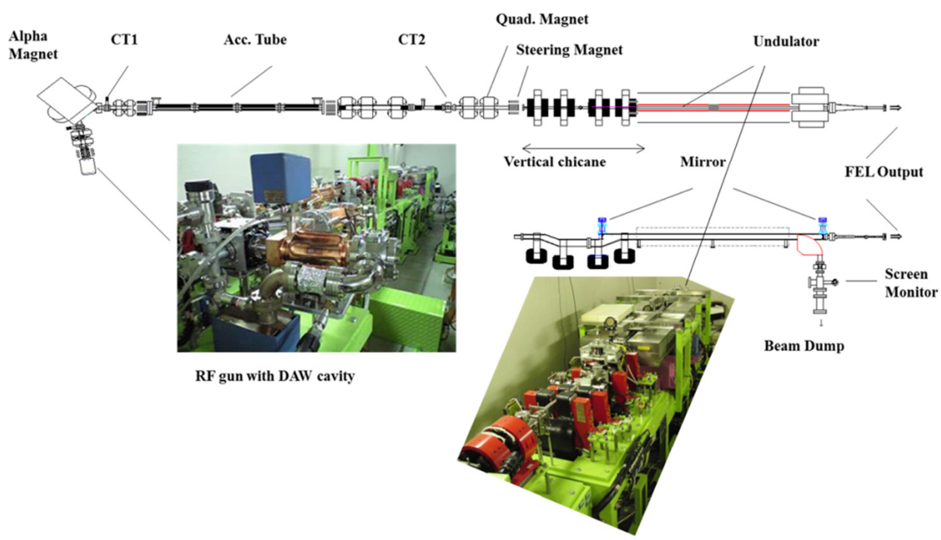

Figure 3: Schematic layout and Photograph of FIR-FEL.

RESEARCH SUBJECTS USING MIR-FEL

The unique properties of MIR-FEL at FEL-TUS are summarized as:

- Wide wavelength tunability in the mid infrared (finger print) region. This enables us to characterize the geometrical structures of molecules, clusters, etc. mainly in the gas phase through vibrational spectroscopy.
- Nearly perfect linear polarization. A good polarization property is required for determination of the alignment of the chemical bonds in molecules adsorbed on surfaces.
- Pulsed lasing structure. A macropulse operating at 5 Hz can be electronically synchronized with the other table-top laser system such as Q-switched YAG laser. A pump-and-probe experiment is essential for understanding dynamical behaviors involved in the various chemical and physical phenomena.
- High photon densities. The high peak power of MIR-FEL readily induces a multiple photon process [2-4] in which molecules (materials in general) absorb many photons within a single laser pulse.

The multiple photon absorption and the subsequent dissociation of simple molecules in the gas phase have been experimentally investigated in details in 1980s using a CO_2 laser. The laser isotope separation, utilizing the difference of the small vibrational frequencies between isotopomers, is one of the good examples of infrared multiple photon dissociation (IRMPD). Recently, an excellent enrichment of ^{13}C by MIR-FEL at FEL-TUS was reported [3] by our group. The starting material is a simple organic molecule ($C_3H_4O_2$) called β-propiolactone which dissociates to ethylene (C_2H_4) and carbon dioxide (CO_2) through IRMPD (see Fig. 4); ^{13}C located between two oxygen atoms is enriched as $^{13}CO_2$. The small mass difference between ^{12}C and ^{13}C yields the shift of frequencies of vibrational modes involving this carbon atom. We measured the ^{13}C enrichment factor (the fraction of $^{13}CO_2$ in the total CO_2 product) as a function of laser wavelength. After the careful selection of the wavelength, the highest ^{13}C atom fraction of 59 % was achieved. The fundamental factors yielding this splendid selectivity might be twofold;

1. A relatively large isotope shift of ~ 47 cm^{-1} for the =C=O stretching vibration around 1880 cm^{-1}, which is larger than the energy resolution of MIR-FEL.

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2. A short micropulse interval (~ 350 ps; see Fig. 5) of MIR-FEL than the collisional frequency of β-propiolactone molecules in the gas phase, which prevents the collisional energy transfer from ^{13}C molecules to ^{12}C molecules during successive micropulses.

The multiple photon absorption was observed not only in the molecules in the gas phase but also in the bulk crystals [2].

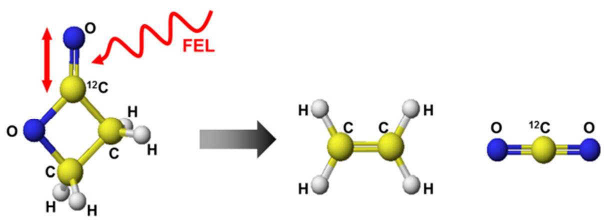

Figure 4: IRMPD of β-propiolactone gives ethylene and carbon dioxide as products.

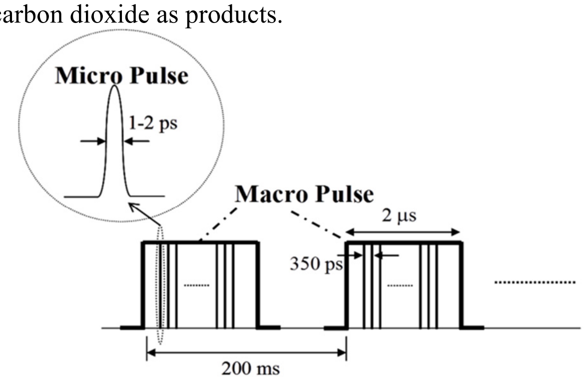

Figure 5: Pulse time structure of MIR-FEL output.

DEVELOPMENT OF FIR-FEL

Besides photo science using MIR-FEL which has been promoted at FEL-TUS, the commissioning of FIR-FEL in order to realize FEL lasing in the THz region is currently in progress.

An RF-gun with Disk-and-Washer (DAW) accelerating cavity which achieves low emittance and reduction of back-bombardment was developed and installed as an electron source in the FIR-FEL beamline. After the electron beam acceleration and transport to the beam dump, the spontaneous emission was successfully detected.

Since it is desirable for FEL lasing to increase the power of spontaneous emission, we introduced thermionic and photo multiple-cathode in order to increase the peak current of the electron beam. With laser irradiation to LaB_6 single crystal used for thermionic cathode, thermionic and photo electron beam is generated simultaneously. High FEL efficiency and higher signal from photo detector for spontaneous emission which leads to easy cavity tuning are expected adopting the multiple-cathode.

A Nd:YAG laser was installed next to the injector of FIR-FEL in the FEL machine room as shown in Fig. 6. A fourth harmonic (266 nm) of the Nd:YAG pulse was injected from the view port of α magnet. The generated thermionic and photo electron beam waveform measured by Current Transformer where located in downstream of α magnet is shown in Fig. 7. The peak current of the generated electron beam is about 250 mA, which is almost 5 times higher than that of thermionic beam.

We will continue the optimization of the irradiation condition in order to obtain a higher peak current and then try to tune the optical resonator towards FEL lasing.

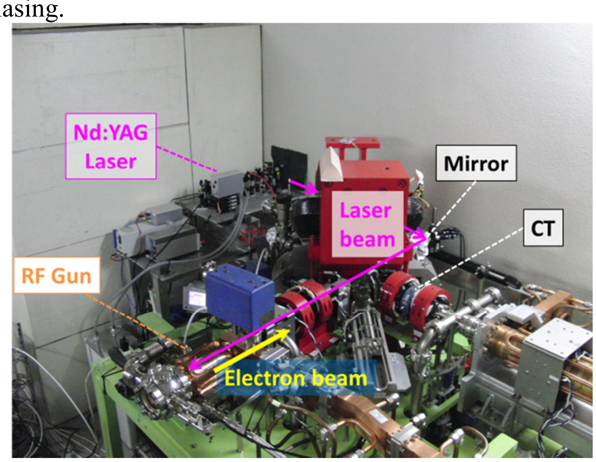

Figure 6: Set up for laser irradiation to thermionic and photo multiple-cathode.

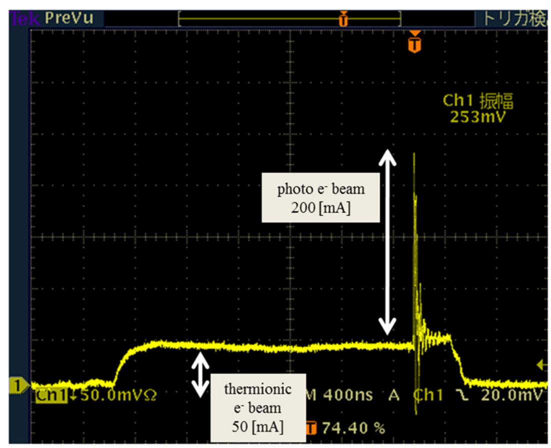

Figure 7: Thermionic and photo electron beam waveform measured by Current Transformer.

ACKNOWLEDGMENT

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