PRESENT STATUS OF MID-INFRARED FREE ELECTRON LASER FACILITY IN KYOTO UNIVERSITY

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Abstract

A Mid-Infrared Free Electron Laser (MIR-FEL) facility named as KU-FEL has been constructed for energy science in Institute of Advanced Energy, Kyoto University. The accelerator of KU-FEL consists of an S-band 4.5-cell thermionic RF gun, a Dog-leg section for energy filtering, a 3-m traveling-wave type accelerator tube, 180-degree arc section for bunch compression and a hybrid undulator. We have already succeeded in lasing of the FEL from 5.5 to 14.5 μm. Present status and recent activity for the FEL development is reported in this paper.

INTRODUCTION

A development work of MIR-FEL facility named as KU-FEL has been started since 1998 in Institute of Advanced Energy, Kyoto University. We aimed at developing a compact and economical FEL facility for energy related science and industrial applications [1]. The construction of the facility was finished in 2006 and the first lasing and power saturation of the FEL have been achieved in 2008 [2, 3]. At that time, the tunable range of KU-FEL was limited to 10–13 μm because of insufficient FEL gain and macro-pulse duration. In order to extend the tunable range, in 2011, the undulator is replaced with another one which has been used for ERL-FEL in JAEA [4]. At the same time, optical cavity mirrors are also replaced [5]. After the replacement, the tunable range has already been extended to 5–14.5 μm. The FEL beam has been provided to various user experiments since 2009. Now the facility is opened to external users under the Joint Usage/Research Program on Zero-Emission Energy Research of Institute of Advanced Energy, Kyoto University.

KU-FEL FACILITY

The KU-FEL is a compact MIR-FEL facility based on compact linec utilizing a thermionic RF gun as the electron source. A schematic diagram of KU-FEL linac is shown in Fig. 1. Multi-bunch electron beam with the energy of 8.4 MeV is generated in the thermionic RF gun driven by a 10-MW klystron. Since the electron beam generated from the RF gun has large energy spread and low energy tail, the energy filtering section is arranged between the RF gun and the accelerator tube. After the energy filter, the electron beam is injected to the 3-m traveling-wave type accelerator tube driven by a 20-MW klystron. After the accelerator tube, the maximum beam energy is around 36 MeV. By using the accelerator tube and 180-deg. arc section, the electron bunch compression is performed. Finally the compressed electron bunches are injected to a 1.8-m undulator to make FEL lasing. The FEL power is extracted from the optical resonator through the out-coupling hole in upstream mirror and transported to user stations as shown in Fig. 2. Now two user stations are available; one is for FEL beam diagnostics and simple irradiation and the other is for spectroscopy of solid state material. The parameters of the rf gun, the accelerator tube, undulator, optical cavity and FEL transport line are written in reference [6], [7], [5], [5] and [8], respectively.

The KU-FEL facility was operated for 570 hours in fiscal year 2012. About 70% of the operational time is used for user experiments.

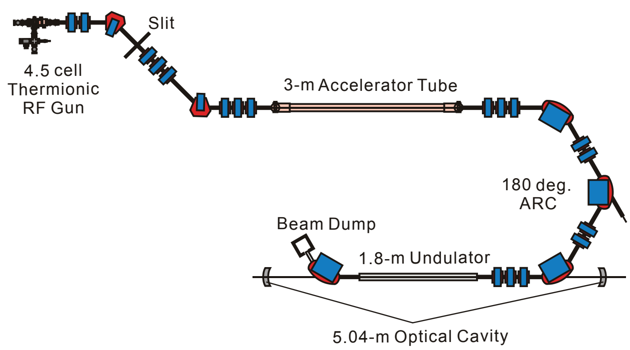

Figure 1: Schematic diagram of KU-FEL linac.

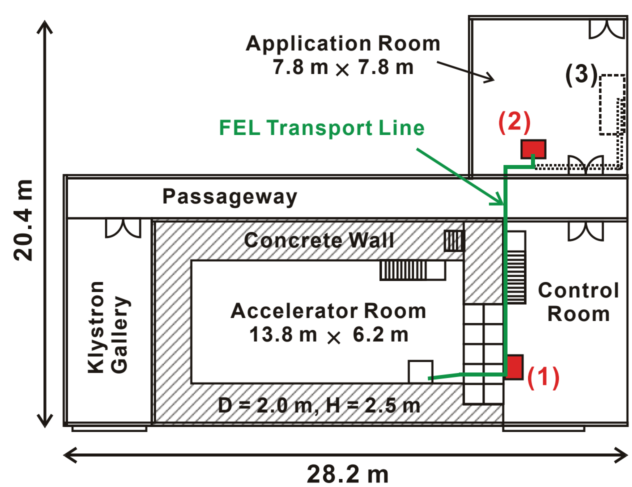

Figure 2: Facility layout including the transport line and user stations. (1) Diagnostics and simple irradiation station. (2) Spectroscopy of solid state material station. (3) Multipurpose station (planning).

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ELECTRON BEAM PROPERTIES

The beam current profiles at the exit of the RF gun, at the entrance of the accelerator tube and at the beam dump are shown in Fig. 3. The electron beam current increases during a macro-pulse due to the back-bombardment effect in the RF gun [9]. In order to reduce the amount of back-bombardment electrons, a technique, "sweep magnet [9]," has already been introduced. Moreover, two techniques, "RF amplitude control [10]," and "cavity detuning [6]," have also introduced to compensate the beam energy drop caused by the beam current increase. By those two techniques, we succeeded in keeping the beam energy and bunch phase constant over the macro-pulse even with quite large beam current increase during a macro-pulse [3, 11].

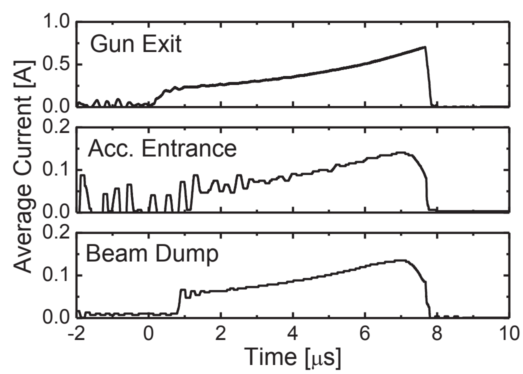

Figure 3: Beam current profiles at the exit of the RF gun (top), at the entrance of the accelerator tube (middle) and at the beam dump (bottom).

OPTICAL BEAM PROPERTIES

The temporal evolutions of electron beam and FEL power are shown in Fig. 4. The normalized spectrums of FEL beam are shown in Fig. 5. As one can see in Fig. 5, KU-FEL can provide monochromatic MIR radiation from 5 to 14.5 μm. Figure 6 shows the one-day history of FEL power. The long term stability was around 15% in FWHM (Fig. 6). And the wavelength stability was measured as 1.3% (root mean square) [12]. The main parameters of the electron beam and optical beam are listed in Table 1.

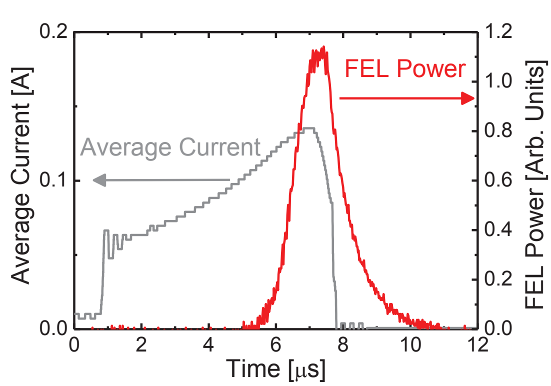

Figure 4: The beam current profile at the undulator section and FEL power evolution.

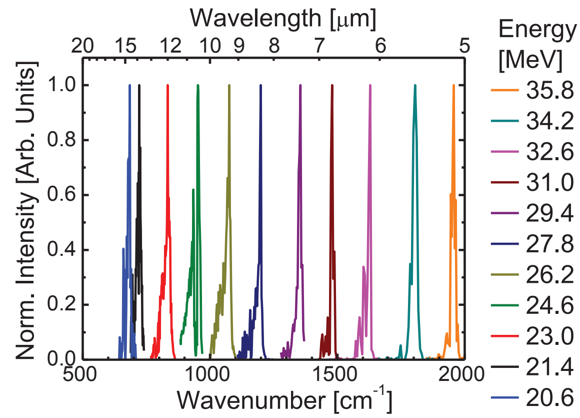

Figure 5: Normalized spectrum of FEL beam driven by electron beam with different energy. The undulator gap was fixed to 19.5 mm and then K-value was 1.05.

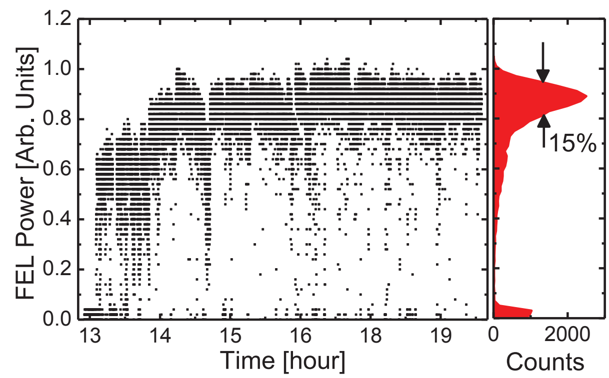

Figure 6: One-day operational history and histogram of KU-FEL output power.

Table 1: Main Parameters of KU-FEL

Electron Beam (at the undulator section)	
Beam Energy	20 – 36 MeV
Average Current	~100 mA
Macro-pulse Duration	6.8 μs
Energy Spread	~1% (FWHM)
Bunch Repetition Rate	2856 MHz
Optical Beam	
Wavelength	5 – 14.5 μm
Macro-pulse Energy	~15 mJ
Macro-pulse Duration	~1.5 μs
Spectrum Width	~3% (FWHM)
Micro-pulse Duration	~0.6 ps*

*Measured at 12 μm [12].

FUTURE UPGRADE

Several research works are running for improving and upgrading the KU-FEL performance.

ISBN 978-3-95450-122-9

Improve Stability

Now the power and wavelength stability of FEL beam were around 15% and 1.3%, respectively. Present stability is enough for several applications such as irradiation to bio-samples, laser induced forward transfer and ablation spectroscopy. However, for precise spectroscopy and isotope separation, higher stability is strongly required. We have installed 6 beam position monitors (BPMs) to measure the fluctuation of the electron beam position in various longitudinal positions of the KU-FEL linac. At the low energy section of the linac, feedback control system has been developed and utilized to stabilize the beam position and energy [13]. And the BPMs will also be used for studying the fluctuation sources.

Introduction of Photocathode RF Gun

We are developing a photocathode RF gun for further improvement of KU-FEL performance. A numerical study has been conducted and predicted drastic increase of peak power of the FEL [14]. The RF cavity of the gun has been already manufactured under the collaboration with KEK-ATF group. The photocathode illumination laser has been developed under the collaboration with Dr. Kuroda, senior research scientist of AIST. First beam from the photocathode RF gun will be generated in this fiscal year. This photocathode RF gun will also be used for R&D of THz seeded SASE FEL [15].

Development of Triode-type Thermionic RF Gun

In 2002, a triode-type thermionic RF gun has been proposed for drastic reduction of back-bombardment electrons in a thermionic RF gun [16]. Several numerical works have been done for evaluation of the reduction effect and designing the prototype cavity and cathode assembly [17-19]. After the designing work, a small coaxial cavity with thermionic cathode has been developed and tested [20]. The resonant frequency of first prototype (2437 MHz) was very far from the operational point of main RF gun and our RF source (2856 MHz). The cavity with frequency tuner was newly designed and manufactured [21]. The cold test with dummy cathode has been carried out [22].

CONCLUSION

An MIR-FEL facility named as KU-FEL has been developed for energy related science. The driver linac is consists of a thermionic RF gun and a 3-m accelerator tube. The back-bombardment effect in the RF gun is well controlled and the linac provides long-macro-pulse electron beam with constant energy and phase even with quite large beam current increase in a macro-pulse. Now the FEL can cover the wavelength range from 5 to 14.5 μm. The power and wavelength stability were 15% in FWHM and 1.3% in RMS, respectively.

For further improvement of FEL performance, several projects are undergoing. The introduction of electron beam feedback control using BPMs will increase the power and wavelength stability of KU-FEL. The introduction of photocathode RF gun will enable us to generate drastically high peak power MIR beam and R&D study on THz seeded SASE FEL. Realization of triode-type thermionic RF gun will not only improve the performance of KU-FEL but also contribute to make the application field of thermionic RF gun much wider than present.

ACKNOWLEDGMENT

This work is partially supported by an “Energy Science in the Age of Global Warming” of Global Center of Excellence (G-COE) program (J-051) and The Collaboration Program of the Laboratory for Complex Energy Processes, Institute of Advanced Energy, Kyoto University.

REFERENCES

[1] T. Yamazaki et al., Free Electron Laser, 2001 (2002), pp. II–13.
[2] H. Ohgaki et al., Jpn. J. Appl. Phys., pp.8091-8094 (2008).
[3] H. Ohgaki et al., Proc. of FEL08, pp.4-7 (2008).
[4] R. Nagai et al., Nucl. Instrum. Methods Phys. Res., Sect. A, 358, pp.403-406 (1995).
[5] H. Zen et al., Proc. of FEL12, WEPD38, to be published.
[6] H. Zen et al., IEEE Transactions on Nuclear Science, 56, pp.1487-1491 (2009).
[7] H. Zen et al., Proc. of EPAC08, pp.1329-1381 (2008).
[8] K. Yoshida et al., Zero-Carbon Energy Kyoto 2012, pp.205-216 (2013).
[9] C.B. McKee et al., Nucl. Instrum. Methods Phys. Res., Sect. A, 296, pp.716-719 (1990).
[10] T. Kii et al., AIP conf. proc., Synchrotron Radiation Instrumentation, pp. 248-251 (2006).
[11] H. Zen et al., Proc. of IPAC10, pp.1725-1727 (2010).
[12] Y. Qin et al., Opt. Lett., 38, pp.1068-1070, (2013).
[13] H. Ohgaki et al., WEPME019, in these proceedings.
[14] H. Ohgaki et al., Proc. of FEL2007, pp.390-393 (2007).
[15] K. Shimahashi et al., Proc. of IRMMW-THz2012, 6380241 (2012).
[16] K. Kanno et al., Jpn. J. Appl. Phys., Supplement, pp.62-64 (2002).
[17] K. Masuda et al., Proc of FEL2005, pp.588-591 (2006).
[18] K. Masuda et al., Proc. of FEL2006, pp.656-659 (2006).
[19] T. Shiiyama et al., Proc. of FEL2007, pp.398-401 (2007).
[20] M. Takasaki et al., Proc. of FEL2010, pp.497-500 (2010).
[21] T. Konstantin et al., Proc of FEL2012, to be published.
[22] T. Konstantin et al., MOPFI020, in these proceedings.

ISBN 978-3-95450-122-9