LASING OF MIR-FEL AND CONSTRUCTION OF USER BEAMLINE AT KYOTO UNIVERSITY

Mahmoud A. Bakr*[1], K. Yoshida[1], K. Higashimura[1], R. Kinjo[1], H. Zen[2], T. Kii[1], T. Sonobe[1], K. Masuda[1], H. Ohgaki[1], Y. U. Jeong[3]
[1]Institute of Advanced Energy, Kyoto University 611-0011 Gokasho, Uji, Kyoto, Japan
[2]UVSOR, Institute for Molecular Science, 38 Nishigo-Naka, Myodaiji, Okazaki, Aichi 444-8585, Japan
[3]Korea Atomic Energy Research Institute, P. O. Box 105, Yusong, Taejon, 305-600, Korea

Abstract

A mid-infrared free electron laser (MIR-FEL) facility (KU-FEL: Kyoto University Free Electron Laser) has been constructed for developing energy materials in Institute of Advanced Energy (IAE), Kyoto University. FEL gain saturation at 13.2 µm has been achieved for the first time in May 2008. Now we are developing the MIR-FEL beamline for wavelength range from5 to 20 µm. The beam profile of the MIR-FEL at the accelerator room has been measured by using a MCT detector to design the beamline. The design of the beamline has been finished and the beam transport line has been constructed to the application room. Applications of the MIR-FEL in the renewable energy research at Kyoto University will be started in this fiscal year as well.

INTRODUCTION

Construction of a MIR-FEL facility (KU-FEL) at the Institute of Advanced Energy, Kyoto University has been finished in 2006[1]. We started FEL oscillation experiments in 2007 and succeeded in the first lasing at a wavelength of 12.4 µm in March 2008[2]. A beam loading compensation method with an RF amplitude control in the thermionic RF gun was used to qualify the electron beam. A developed feedforward RF phase control was applied to stabilize the RF phase shifts. Detuning method also has been developed to sustain the macro-pulse length of the electron beam up to about 5 µs[3]. As a result FEL gain saturation at 13.2 µm has been observed for the first time at May 2008. In order to start application in chemistry and renewable energy science we start to construct the MIR beamline. As for a pilot application of MIR- FEL to optical properties measurement, an in-situ photoluminescence (PL) spectra measurement system for TiO_2 during FEL irradiation has been developed in order to investigate the effects of FEL on photoexcitation process, which possibly gives rise to find more precise information of photoelectric conversion mechanism.

LASING EXPERIMENTS SETUP AND RESULTS

KU-FEL system consists of an S-band 4.5-cell thermionic RF gun driven by a 10 MW klystron, a 3 m accelerator tube driven by a 20 MW klystron, a beam transport system, and a Halbach type undulator of 1.6 m. Fig.1 shows diagram of KU-FEL facility and MIR-FEL beam transport line from the accelerator room to the application room.

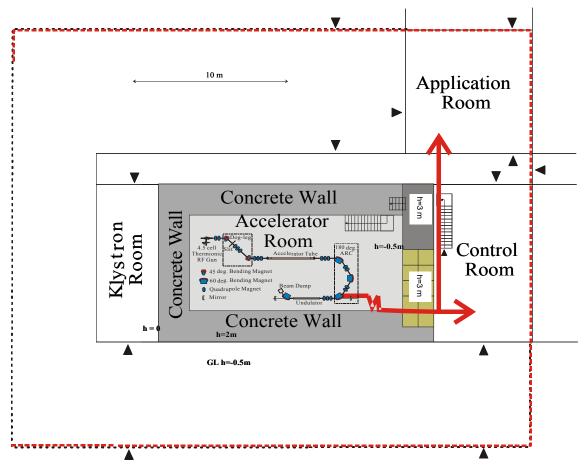

Figure 1: Diagram of KU-FEL facility and MIR-FEL beam transport line.

A LaB_6 thermionic cathode of 2 mm diameter was employed to produce a high-brightness electron beam. An achromatic transport system (dogleg section in Fig.1) consists of a 45° bending magnet and an energy slit, three quadrupole magnets and another dipole magnet, and it serves as an energy analyzer[4]. The energy slit was set to select the electron beam of about 3% energy spread. An S-band accelerator tube accelerates the electron beam up to 40 MeV using a 20 MW RF power. For the saturation experiment the electron beam energy was 23.9 MeV. The beam parameters were optimized to obtain the maximum FEL gain using a simulation code, GENESIS[5].

The 180° arc designed for a bunch compressor[4] was tuned to obtain a high peak current of the electron beam. Thus the micropulse peak current was estimated form simulation to be around 38 A. Two triplet quadrupoles located on both sides of the 180° arc worked as a beta-match component between the linac and the undulator. A planar-type undulator, which was used for the experiment in the collaboration between FELI and the University of Tokyo[6], was used. The undulator length was 1.6 m, the period was 40 mm, number of periods was 40 and the undulator parameter K-value was varied from 0.99 to 0.17

* m-a-bakr@iae.kyoto-u.ac.jp

by changing the gap of the undulator. In this experiment, we used a 0.99 K-value to maximize the FEL gain in our system. The optical resonator consists of a pair of gold-coated Cu mirrors with 99.04% reflectivity, the upstream mirror of which has a coupling hole of 2 mm ϕ. The horizontal and vertical normalized emittances measured by a tomographic method[7] were 4 πmm-mrad and 12 πmm-mrad at the undulator, respectively. Since the RF frequency was 2856 MHz in the KU-FEL linac, the cavity length was set to 4.516 m using a set of five-axis mirror manipulators whose scanning resolution in the longitudinal direction was 1 µm.

To achieve the gain saturation in MIR-FEL a beam loading compensation method with an RF amplitude control in the thermionic RF gun was used to qualify the electron beam. We also developed and applied a feedforward RF phase control to stabilize the RF phase shifts during the macro-pulse which was induced from RF amplitude control.

The FEL signal was measured with an MCZT IR detector (HgCdZnTe, PDI-2TE-10.6, Vigo System). Fig. 2 shows the light output signal as well as the electron beam current during the experiment. FEL gain was estimated from the exponential growth of laser output signal to be 22% and optical loss was estimated from the decay of laser output signal to be 10% which include detector response of about 100 ns. Therefore, the total FEL gain was 32% as shown in Fig. 2. An approximately 10^7 W output power could be expected with a 4.5 µs buildup time, which corresponds to the electron beam used in the experiment. 3D simulation with a modified GENESIS was performed from a RF gun to FEL. In this simulation, the realistic geometry of the KU-FEL optical cavity including vacuum chamber was taken in consideration. The results of these calculations indicated the total gain around 31% and this value agrees well with the experimental values.

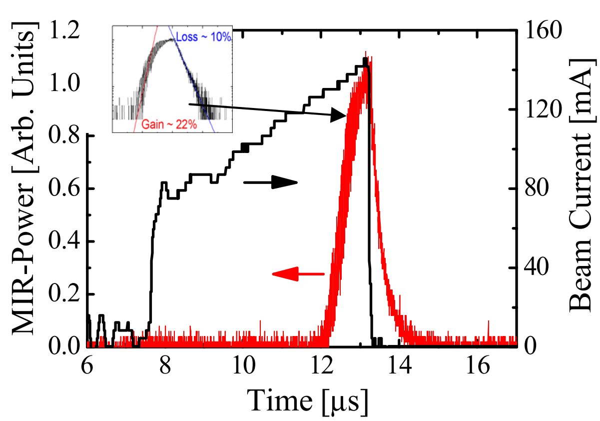

Figure 2: The temporal profile of the beam current and MIR-power

Pyroelectric energy detector (818E-20-50S) was used for quantitative evaluation of the radiation energy per pulse. The voltage signal from the detector was amplified by using Multi-Function optical meter (1835-C, Newport) the absolute pulse energy was around 4.6 mJ/macropulse.

The long term stability within 30 minutes, and the fluctuation in FWHM in the energy histogram were measured, the results indicated that the radiation energy get stable and the fluctuation was around 15%. The wavelength spectrum was measured by a monochromator (Digikrom, Dk240) and MCT detector. The peak wavelength was around 13.2 µm and the line width was 1.8% at FWHM.

BEAMLINE DESIGN

At first we measured the beam profile of the MIR-FEL at the accelerator room to design the beamline by using MCT detector. The beam size was about 4.5 mm (FWHM) at 640 mm downstream of the out coupling hole (2 mm in diameter). Therefore the beam divergence is deduced to be 7 mrad. Then, FEL output extracted from the optical cavity is converted to parallel beam by using concave spherical mirror with focal length of 2 m as shown in Fig. 3. The parallel beam is transported to the experiment room by the deflection on 6 flat mirrors as shown in Fig. 4, additional 3 flat mirrors are used to transport the beam to the application room. Actuators are used for adjusting the angles of mirrors to deflect parallel beam. The parallel beam will be passed through PE pipe with 60 mm diameter, which is filled with dry nitrogen to avoid laser power absorption by the water vapor.

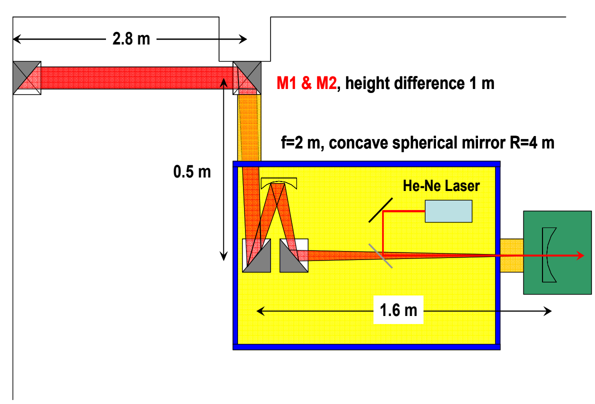

Figure 3: Schematic drawing of the beam expander.

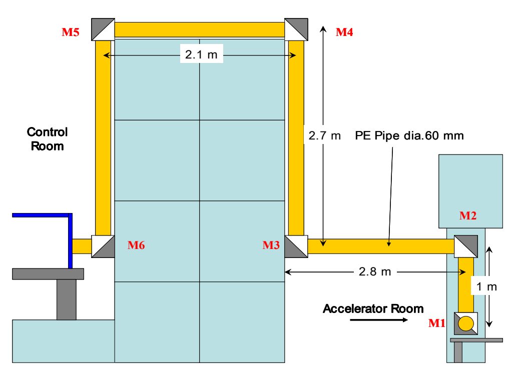

Figure 4: A diagram of MIR-FEL beamline.

Preliminary measurements to the optical energy in the control room was done, Fig. 5, shows the output signal of the power meter detector. The measured laser power in the control room was 0.6 mJ/pulse. Since we did not measure the laser power at accelerator room simultaneously, the transition rate of the laser has not been confirmed yet.

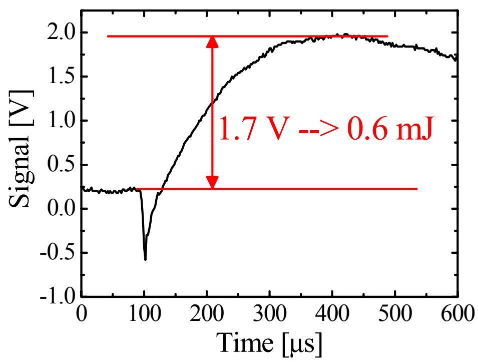

Figure 5: Preliminary measurements for the energy at the experiment room.

MIR-FEL APPLICATIONS IN THE RENEWABLE ENERGY RESEARCH

As for a pilot application of MIR- FEL to renewable energy study, a new approach of material evaluation has been developing at our research group. In this study, we focused on the TiO_2 since it has been widely applied for renewable energy related materials such as solar cells, and photoanode for splitting of water to produce hydrogen fuel. Especially TiO_2 solar cell has several advantages such as its low cost and non toxicity of the raw material compared with silicon solar cell. In order to produce TiO_2 solar cell with high photoelectric conversion efficiency, it is important to understand the photoelectric conversion mechanisms through evaluating its energy bands structure in details. In this on going study is aimed at the better understanding of the energy band structure of the TiO_2, by use of FEL, and at development of KU-FEL application for energy material science. Fig. 6 shows a plan view of two lasers optical measurement system by FEL, which consists of KU-FEL and He-Cd laser (Kinmon, IK5451R-E), and monochromator (NOS-Omini-λ3008).

CONCLUSION

We have been developed MIR-FEL facility for renewable energy science in IAE, Kyoto University. An amplitude-modulated RF power, beam loading compensation system and a phase stabilization system in both the thermionic RF gun and the accelerator tube were developed and applied in the KU-FEL. As a result, we succeeded to achieve FEL gain saturation at 13.2 µm with our FEL device.

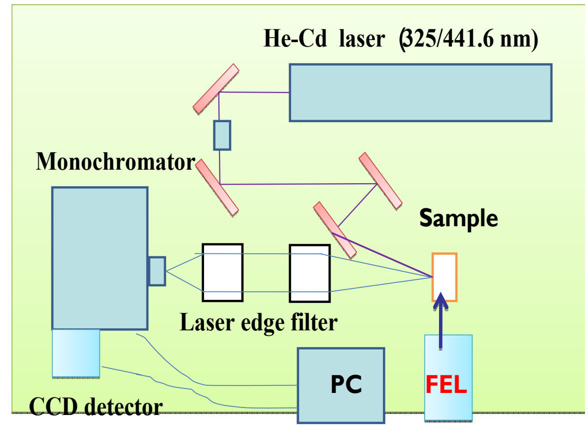

Figure 6: A plan view of optical measurement system by FEL

The FEL gain estimated from the temporal profile was around 32%. The beam profile was measured and beam transport line has been designed and constructed.

The preliminary measurements of FEL at the control room indicated that we succeed to transport the FEL from the accelerator room to the experiment room using six flat mirrors. We will extend the beamline to application room and start experiments on the MIR-FEL applications in the renewable energy research.

REFERENCES

[1] H. Zen, T. Kii, K. Masuda, H. Ohgaki, and T. Yamazaki: Infrared Phys. Technol. 51 (2008) 382-385.
[2] H. Ohgaki, T. Kii, K. Masuda, H. Zen, S. Sasaki, T. Shiyama, R. Kinjo, K. Yoshikawa, and T. Yamazaki, Japanese Journal of Applied Physics, Vol. 47, No. 10, 2008, pp. 8091–8094.
[3] H. Zen, H. Ohgaki, T. Kii, K. Masuda, S. Sasaki, T. Shiyama, R. Kinjo, K. Yoshikawa, and T. Yamazaki, to be printed in IEEE TNS.
[4] H. Ohgaki, I. Tometaka, K. Yamane, T. Kii, K. Masuda, K. Yoshikawa, and T. Yamazaki: Nucl. Instrum. Methods Phys. Res., Sect. A 507 (2003) 150-153.
[5] S. Reiche: GENESIS v1.3 User Manual.
[6] E. Nishimura, K. Saeki, S. Abe, A. Kobayashi, Y. Morii, T. Keishi, T. Tomimasu, R. Hajima, T. Hara, H. Ohashi, M. Akiyama, S. Kondo, Y. Yoshida, T. Ueda, T. Kobayashi, M. Uesaka, and K. Miya: Nucl. Instrum. Methods, Phys. Res., Sect. A 341 (1994) 39-42.
[7] H. Zen, H. Ohgaki, K. Masuda, T. Kii, K. Kusukame, T. Fukui, Y. Nakai, T. Yamazaki, and K. Yoshikawa: AIP Conf. Proc. 879 (2007) 240-243.