STATUS OF THE MIR-FEL FACILITY IN KYOTO UNIVERSITY

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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. A beam loading compensation method with feedforward RF phase control has been developed to supply the required quality of electron beam. The FEL beam characterization has been performed. The macro pulse energy of 5 mJ/pulse and the peak power of about 3 MW has been measured. The FEL transport system of wavelength range from 5 to 20 μm has been constructed to the application room. Applications of the MIR-FEL in the renewable energy research at Kyoto University will be started within this financial year.

INTRODUCTION

IR tunable coherent light is a useful tool for the study of molecular dynamics, because such light can excite specific stretching bands[1], e.g., C=N, C=O, and Si-H, which are useful for the production of renewable energy sources, i.e., the production of alcohol or hydrogen and the development of next-generation solar cells. Thus, a mid-infrared free-electron laser facility (KU-FEL) has been constructed at the Institute of Advanced Energy, Kyoto University[2]. The construction of the facility was finished in 2006[3]. We started FEL oscillation experiments in 2007 and succeeded in the first lasing at a wavelength of 12.4 μm in March 2008[4]. 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[5]. Finally, an FEL gain saturation has been achieved in May 2008[6]. In order to start MIR-FEL application in energy science we start to beam characterization of FEL and to construct the beam transport system. In this paper, we will report on the result of the FEL beam characterization and current status of the facility and including a pilot application in KU-FEL.

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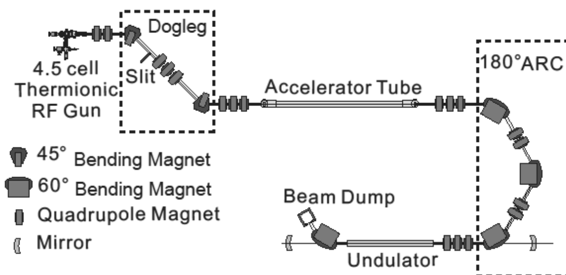

Figure 1: Schematic drawing of KU-FEL.

FEL BEAM CHARACTERIZATION

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. 3D simulation with a modified

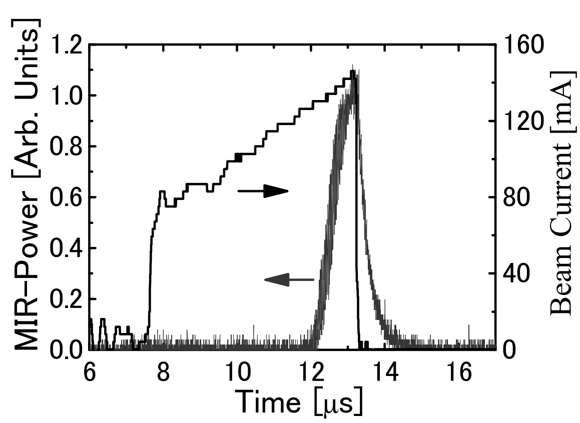

Figure 2: Temporal profile of the beam current and MIR-power at the gain saturation condition.

GENESIS[7] 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.

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 wavelength spectrum was measured by a monochromator (Digikrom, Dk240) and MCT detector. The peak wavelength was 13.2 µm and the linewidth was 240 nm (1.8%) in FWHM. The micro-pulse duration was estimated to be less than 1 ps with measurements by a streak camera and an interferometer. Table 1 shows main parameter of the FEL beam.

Table 1: Main Parameters of the FEL Beam

Wavelength (µm)	13.2
σ_λ/λ (%)	1
Average Power (mW)	4.6
Peak Power (MW)	2*

*assumed 1 ps pulse duration

FEL BEAM TRANSPORT SYSTEM

The beam profile of the MIR-FEL at the accelerator room was measured to design the FEL transport system. As is shown in Fig.3, 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. 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. 4. Then the parallel beam is delivered to the control room or the application room which is located at 10 m apart from switching mirror (M6). 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 will be filled with dry nitrogen to avoid laser power absorption by the water vapour.

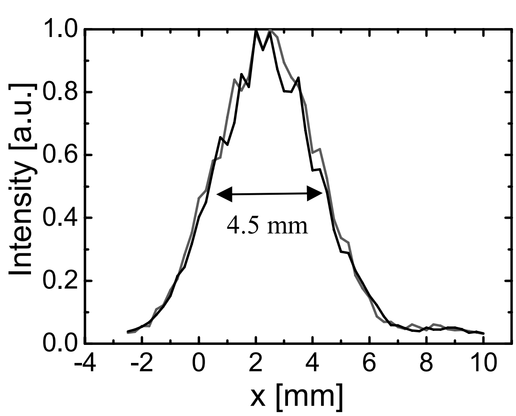

Figure 3: Beam profiles at 640 mm downstream of the outcoupling hole. Red line shows the vertical beam profile and black line shows the horizontal one.

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

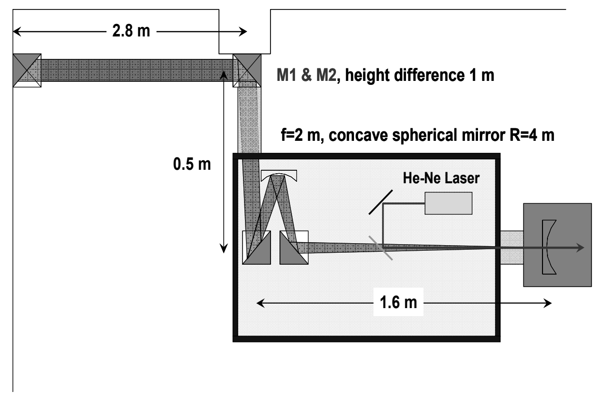

Figure 4: Schematic drawing of the beam expander.

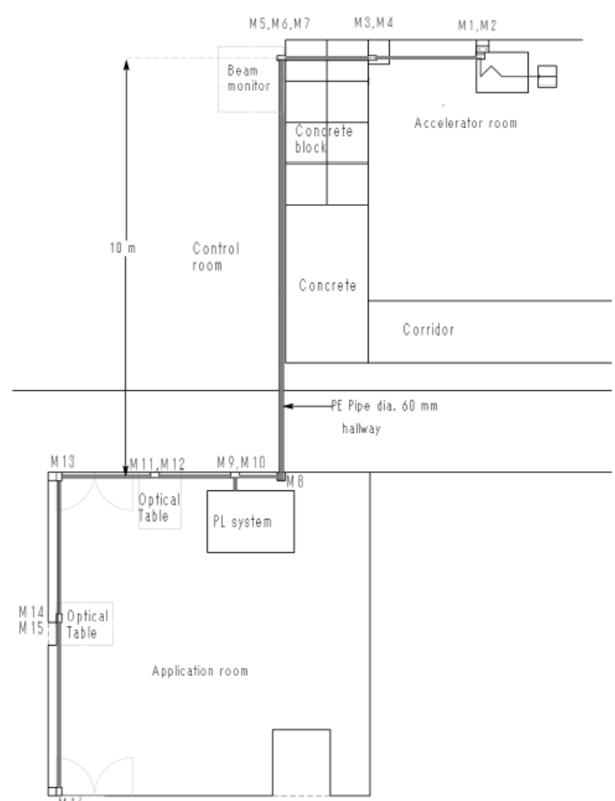

Figure 5: A diagram of MIR-FEL Beam Transport System.

been developing. 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 ongoing 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).

FURTHER DEVELOPMENT

To extend the wavelength range, we are going to install a 1.8-m undulator[8] which has been used for FEL experiment in JAEA Super Conducting linac. A preliminary calculation of the FEL gain has been performed by using GENESIS. During the calculation we assumed the fixed electron beam parameter which was observed in the saturation experiment in KU-FEL except for the electron energy, while the undulator K-value was fixed as 1.5. Figure 7 shows the result of simulation. As a comparison the gain of the present undulator is also plotted. The expected FEL gain is about twice of the present undulator whose maximum K-value is 1 and length of 1.6 m. The expected wavelength ranges from 5 to 21 μm by using. Table 2 shows the main parameters of the 1.8-m undulator. The installation of the 1.8-m undulator is scheduled at the end of this financial year.

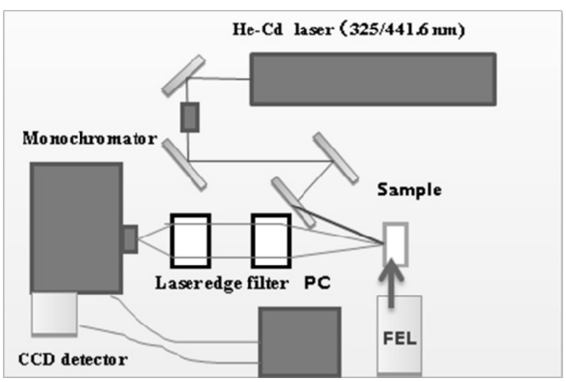

Figure 6: TiO_2 evaluation apparatus.

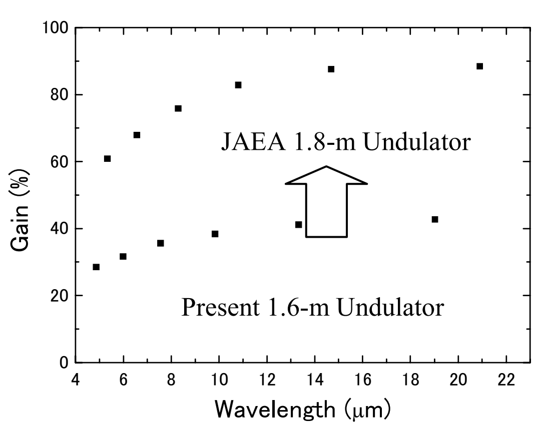

Figure 7: FEL gain with the present undulator and the JAEA 1.8-m undulator calculated by GENESIS.

Table 2: Main Parameters of the JAEA 1.8-m Undulator

Period Length (cm)	3.3
Period	52
Gap Range (cm)	1.5-10
Maximum K-value	1.5
Peak Field (T)	0.5

Research on the thermonioc cathode material is underway[9]. In terms of the backbombardment effect, a lighter cathode material could be suitable for the thermionic RF gun where large amount of backstreaming electrons deposit their kinetic energy as a heat source. Since the lighter material shows smaller stopping power, we can expect smaller change in the cathode surface current density during the macro-pulse. Calculation of such current growth (ΔJ) of 3 cathode materials, LaB_6, CeB_6, and CaB_6 has been performed. We assumed 5 μs macro-pulse duration and the initial temperature (T_0) was set to the same current density(10 A/cm^2). We also assumed that backstreaming electrons had uniform energy of 30 keV which was based on PARMELA simulation. As is shown in Table 3, CaB_6 could be a good candidate for the thermionic cathode material. However, this result only came from the current density growth from backstreaming electron. Cathode material should have a long life-time, an enough current density with a low operation temperature, easy handling, and so on. Further researches will be carried out to develop a suitable cathode material for the thermionic cathode RF gun in our facility.

We also plan to install the Michelson interferometer into the optical cavity to narrow the linewidth of the FEL.

Table 3: Current Density Growth of 3 Hexaborite Materials

Material	CaB_6	LaB_6	CeB_6
T_0 (K)	2340	1910	2100
ΔT (K)	48	190.9	200.9
ΔJ (A/cm^2)	4.1	44	30.33

CONCLUSION

We have succeeded in lasing at 12-13 μm MIR-FEL in the KU-FEL, which is dedicated for research on renewable energy sources in IAE, Kyoto University. The FEL beam characterization has been performed and about 5 mJ/pulse power of 1% bandwidth laser can be available. The FEL beam transport line has been installed to the application room. A pilot application of our FEL beam in the field of energy material is under construction.

Further developments for extend the FEL wavelength range and for stable operation are planned. In the present stage, the stability of FEL output is about 15% for 30 minutes operation. A 1.8-m undulator will be installed in this financial year. Study on cathode material is also under way. These new trials could be brought KU-FEL to contribute for developments on the energy materials.

ACKNOWLEDGEMENT

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