DEVELOPMENT OF LINAC-BASED MIR/THz FEL FACILITY AND PHOTOCATHODE RF-GUN IN THAILAND

K. Buakor, N. Chaisueb, K. Damminsek, J. Saisut, C. Thongbai, W. Thongpakdi, S. Rimjaem*,
Plasma and Beam Physics Research Facility, Department of Physics and Materials Science,
Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand

Abstract

A linac-based MIR/THz free-electron laser facility is under the development at the Plasma and Beam Physics Research Facility, Chiang Mai University. The ultimate goal of the project is to generate the infrared radiation covering the wavelengths from 13 to 125 µm. The main applications of the radiation involved MIR/THz imaging and spectroscopy. The future FEL facility will consists of an injector system, an experimental station for coherent transition radiation, two magnetic bunch compressors and two undulator magnets equipped with optical cavities for MIR and THz beamlines. An expected electron beam energy is between 10 to 20 MeV with an energy spread of about or less than 1 %. Two undulator magnets with maximum undulator parameters of 1 and 0.95 will be used for generation of the THz-FEL and MIR-FEL, respectively. In this paper, we present the status of the design and construction of this future FEL facility.

INTRODUCTION

An accelerator-based MIR/THz free-electron laser facility is constructing at the PBP-CMU Linac Laboratory of the Plasma and Beam Physics (PBP) Research Facility, Chiang Mai University, Thailand. The main purpose of the facility is to generate infrared radiation in wavelengths from 13 to 125 µm. The radiation with this wavelength range has various applications involved MIR/THz spectroscopy and imaging.

Generally, the FEL radiation can be generated from high quality relativistic electron bunces, which travel through an undulator magnet. The undulator radiation is amplified by an optical cavity combined with two high reflectivity mirrors at both side of the undulator magnet [1-4]. An electron injector system for the future MIR/THz facility will be developed from the existing linac system in order to minimize the cost and the effort to construct a new facility. The current injector system consists of an S-band standing wave thermionic RF-gun, a bunch compressor in a form of an alpha magnet, and an S-band travelling-wave linear accelerator with other related components in a beam transport line. This system was constructed to produce a few hundreds femtosecond electron bunches for generation of the coherent transition radiation [5].

The future MIR/THz FEL facility will consist of the injector system, the experimental station used for coherent transition radiation (CTR), two magnetic bunch compressors and two undulator magnets with their associated optical cavities. The FEL beamlines will be used for producing the radiation with the wavelengths in MIR and THz regimes. The schematic layout of the future accelerator system and the FEL beamlines is shown in Fig. 1.

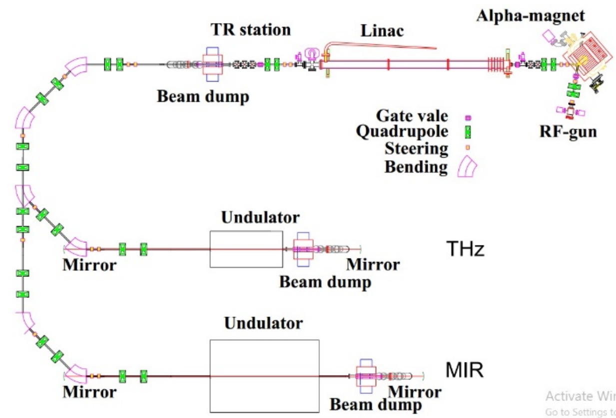

Figure 1: Schematic layout of the future MIR/THz FEL Facility at the PBP-CMU Linac Laboratory, Chiang Mai University.

The entire facility will be located inside the underground experimental hall with radiation shielding wall. The PBP-CMU Linac Laboratory will be the first laboratory in Thailand and South East Asia that develops the FEL facility. Therefore, it will promote the use of electron accelerator and FEL technology in Thailand and neighbors. As a result, opportunities in wide applications of the MIR and THz FEL will be certainly opened in this area

INJECTOR SYSTEM

The electron source in the injector system is a thermionic RF-gun, which can produce electron bunch trains of 2856 micro-bunches per microsecond. The microbunches have a spacing of around 350 ps between each bunch. A longitudinal length of electron bunch at the gun exit is around 100 ps with an average energy of about 2 MeV. A useful fraction of the bunch is filtered by energy slits when the electron beam traverses through the alpha magnet. Moreover, the electron bunch is compressed on the alpha magnet to have a bunch length of a few ps. Then, the beam travels through the linac and is accelerated to have a beam energy of around 20 MeV. The aim of the future facility is the operation with two modes for CTR and for FELs. Some upgrades in the injector system have to be considered. For the CTR experimental station after the linac, the simulation shows

*sakhorn.rimjaem@cmu.ac.th

ISBN 978-3-95450-182-3

that the electron bunch with a maximum charge of 81.6 pC and a longitudinal length (σ_τ) of around 180-430 fs can easily be achieved. For the generation of the FELs, more than one undulator magnets are required to cover the desired radiation spectrum range of MIR and THz. The THz-FEL is firstly considered to be constructed in the near future.

The electron beam from the linac will be turned around by a 180^{o} achromat magnetic bunch compressor to lead the beam to the undulator magnet (as shown in Fig. 1). The bunch compressor system will consist of four 45^{o} defecting angle dipole magnets and three sets of doublet quadrupoles for controlling the electron traveling paths.

Beam dynamics simulation of the future injector system is conducted with the programs PARMELA [6] and ELEGANT [7]. The simulation including the space-charge effects for electrons traveling inside the RF-gun was performed by using the program PARMELA. Then, the program ELEGANT was used to investigate the motion of electrons from the RF-gun exit to the undulator entrance without the space-charge effect. The results show that the electron beam with a bunch charge of 81.6 pC, a longitudinal bunch length of 2.97 ps, an average energy of 10.2 MeV, an energy spread of 0.2% and a horizontal and a vertical emittances of 30.5 and 3.2 mm-mrad can be expected at the undulator entrance. Further study with space-charge effects will be performed to achieve ultimate goal parameters of the electron beam at the undulator entrance, which are listed in Table 1. More optimization is certainly needed to improve the horizontal emittance.

Table 1: Goal and Simulated Properties of the Electron Beam for the Injector System at the Entrance of THz Undulator Magnet

Property	Goal value	Simulated value
Bunch charge	50 pC	81.6 pC
RMS transverse size	0.5 mm	0.6 mm (x-axis) 0.3 mm (y-axis)
RMS bunch length	1 ps	2.97 ps
Beam energy	10 MeV	10.2 MeV
Energy spread	1 %	0.2 %
Normalize transverse emittance	3 mm-mrad	30 mm-mrad (x-axis) 3.2 mm-mrad (y-axis)

PHOTOCATHODE RF GUN

The quality of electron beam from the injector system is considered to be improved for better radiation production. According to advantages of the photocathode RF-gun, the plan to adapt the present thermionic RF-gun to be photocathode RF-gun is ongoing. The emitted electrons from the photocathode are controlled by a short-pulse laser. Therefore, there is no back-bombardment effect, which can damage the cathode surface and increase the effect of electron beam loading. Moreover, the photocathode RF-gun can produce a high charge electron beam with small transverse beam emittance.

In this research, we study on beam dynamics simulation with program ASTRA [8]. The electric and magnetic field distributions inside the RF gun that we import in the simulation were obtained from SUPERFISH program [9]. The wavelength and pulse length of laser pulses used in the simulations are 266 nm and 7.5 ps at FWHM, respectively [10]. A copper (Cu) cathode was used in this study. The parameters of atomically clean copper used for all simulations in this research are obtained from Ref. [11].

The emitted electrons from the photocathode are essentially produced by short-pulse laser. Therefore, an initial electron distribution, which determines kinetic energy, bunch charge, beam transverse size and bunch length, depends greatly on the laser properties. The laser properties used to define the initial particle distribution in the program GENERATOR [8] are listed in Table 2. These parameters are based on the specification of laser system for the photocathode RF-gun of the compact THz-FEL facility at Kyoto University [10].

Table 2: Parameters of the Injected Laser Pulses, which Were Used as Based Information for Initial Particle Distribution in GENERATOR Program

Parameter	Value
Wavelength of injected laser	266 nm
E_{photon} at laser wavelength of 266 nm	4.66 eV
Pulse duration at FWHM	7.5 ps

The simulations were performed by using the laser pulse with the longitudinal Gaussian distribution and the radial uniform transverse distribution. The interested properties of the simulated electron bunch are charge per bunch, transverse beam size, bunch length, beam energy, an energy spread and transverse beam emittance. Dependencies of an average energy and energy spread on the RF phase, for a bunch charge of 100 pC, were investigated. The results in Fig. 2 show that the maximum average beam energy of around 2.4 MeV and the energy spread of around 60 keV were obtained at RF phase of 13^{o}.

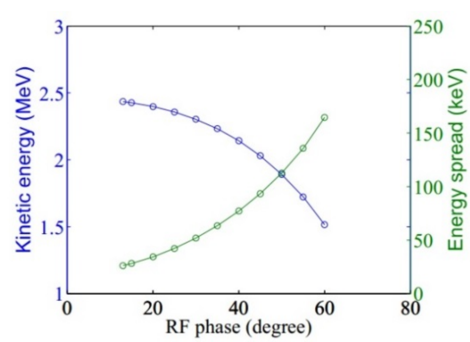

Figure 2: Dependencies of an average energy and an energy spread on the RF phase.

Relation between a laser transverse size and a transverse emittance at the RF-gun exit is shown in Fig. 3.

The beam with a bunch charge of 100 pC and an average beam energy of 2.4 MeV has the smallest emittance of around 1.1 mm-mrad when using a laser spot size of about 0.30 – 0.45 mm.

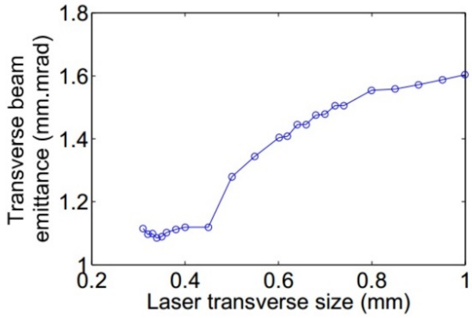

Figure 3: Relation between a laser transverse size and a transverse emittance at the RF-gun exit.

The solenoid magnetic field is applied for transverse beam focusing and emittance conservation. In this study, the center of the solenoid magnetic field is located at 12.45 cm downstream the photocathode. The solenoid magnetic field optimization are shown in Fig. 4. The electron bunch focused by the proper solenoid field has conserved emittance value along the z-position after 0.3 m downstream the gun exit. The results show that the proper solenoid field for the electron bunch with a bunch charge of 100 pC is around 85 mT.

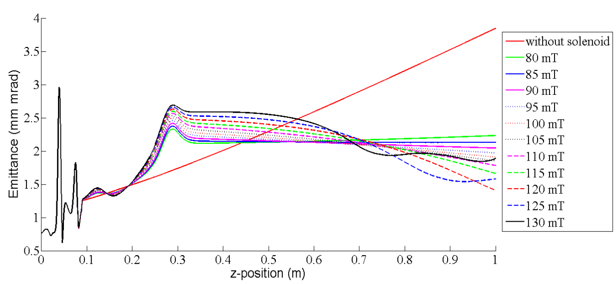

Figure 4: Simulated transverse emittance along the z-position for different solenoid magnetic fields when using a bunch charge of 100 pC and an average beam energy of 2.4 MeV.

DEVELOPMENT OF UNDULATOR MAGNET

A. THz-FEL Undulator

A compact planar electromagnetic undulator for the THz-FEL is developed. The design was conducted by using the programs POISSON [12] and RADIA [13]. The undulator prototype with 13 poles was constructed. It has a pole gap of 10.5 mm and a period length of 64 mm. The peak magnetic field and the undulator parameter (K) can be varied by adjusting the applied current from the power supply. The results of magnetic field measurements show that the peak field can be varied from 50 to 167 mT, which corresponds to the undulator parameter of 0.3 to 1.0. By using this undulator, a 10 MeV electron beam will be able to radiate the THz radiation with the wavelengths between 87 and 125 µm. The future 35-period undulator magnet will be constructed for generating the THz-FEL. Specifications of the THz-FEL undulator magnet are listed in Table 3.

B. MIR-FEL Undulator

With a collaboration between the Plasma and Beam Physics Research Facility and the Institute of Advanced Energy, Kyoto University, Japan, the MIR-FEL undulator was delivered to the PBP-CMU Linac Laboratory in April 2017. It is a planar Halbach permanent undulator magnet. Specifications of this MIR-FEL undulator are listed in Table 3. For this magnet, the undulator parameter can be varied by adjusting the magnetic gap from 26 to 45 mm. Therefore, a peak magnetic field can be obtained from 4.5 to 260 mT. This peak fields correspond to the undulator parameters of 0.17 to 0.95. A 20 MeV electron beam will be able to produce the MIR-FEL with a wavelength between 13 and 19 µm.

Table 3: Specification of the THz-FEL and the MIR-FEL Undulator Magnets

Specification	THz electromagnet undulator	MIR permanent undulator
type	planar	planar Halbach
Magnetic gap	10.5 mm	26-45 mm
Total length	2.24 m	1.6 m
Number of periods	35	40
Period length	64 mm	40 mm
Peak magnetic field	50-167 mT	4.5-260 mT
Undulator parameter (K)	0.3-1.0	0.17-0.95

CONCLUSION

In development of the MIR/THz FEL facility at Chiang Mai University, the existing electron injector will be modified in order to produce the electron beams with proper properties for generation of FELs with the wavelengths in MIR and THz regimes. The optimization of electron beam properties for the THz-FEL beamline was firstly performed. Design and construction of all components for the future MIR/THz-FEL facility are ongoing. The radiation wavelengths of 87-125 µm and 13-19 µm are expected. The study on adapting the present thermionic RF-gun for the photocathode operation was studied. The results show that the emittance of the electron bunch focused by the solenoid field of around 85 mT is nearly conserved after 0.3 m downstream the gun exit. The emittance is as small as 2.2 mm.mrad with an average energy of 2.4 MeV at 1.0 m downstream the cathode.

ACKNOWLEDGMENTs

The authors would like to acknowledge the supports by the Development and Promotion of Science and Technology talents project (DPST), Department of Physics and Materials Science, Faculty of Science, Chiang Mai University, the Thailand Center of Excellence in Physics and the Institute of Advanced Energy, Kyoto University, Japan.

ISBN 978-3-95450-182-3

REFERENCES

[1] P. Michel *et al.*, in *Proc. 28th Int. Free Electron Laser Conf. (FEL2006)*, Berlin, Germany, 2006, paper TUCAU02, pp. 488-491.

[2] W. Schellkopf, et al., in *Proc. 33rd Int. Free Electron Laser Conf. (FEL2011)*, Shanghai, China, 2011, paper TUPB30, pp. 315 -317.

[3] H. Zen *et al.*, *Infrared Phys. Technol.*, vol. 51, pp. 382.

[4] T. Kii *et al.*, in *Proc. Int. Particle Accelerator Conf. (IPAC'10)*, Kyoto, Japan, 2010, paper TUPE028, pp. 2203-2205.

[5] C. Thongbai *et al.*, *Nucl. Instrum. Methods A*, vol. 587, pp. 130, 2008.

[6] L. M. Young and J. H. Billen, "PARMELA", Los Alamos, National Laboratory Technical Note LA-UR-96-1835, 2002.

[7] ELEGANT, `http://www.apa.anl.gov`

[8] K. Flöttman, "ASTRA Particle Tracking Code", `http://www.desy.de/~mpyflo/`

[9] L. M. Young and J. H. Billen, "SUPERFISH", Los Alamos, National Laboratory Technical Note LA-UR-96-1834, 1999.

[10] H. Zen *et al.*, in *Proc. 36th Int. FreeElectron Laser Conf. (FEL2014)*, Basel, Switzerland, 2014, paper THP045, pp. 828-831.

[11] D. H. Dowell *et al.*, *Phys. Rev. ST Accel. Beam*, vol. 9, pp. 063502, 2006.

[12] POISSON, `http://laacg.lanl.gov/laacg/services/download_sf.phtml`

[13] RADIA, `http://www.esrf.eu/Accelerator/group/InsertionDevices/Software/Radia`