ISBN: 978-3-95450-179-3 doi:10.18429/JACoW-FEL2017-MOP048

A COMPACT THz FEL AT KAERI: THE PROJECT AND THE STATUS

S. Miginsky†[1], S. Bae, B. Gudkov, K. H. Jang, Y. U. Jeong, K. Lee, J. Mun, S. Saitiniyazi,
Korea Atomic Energy Research Institute, Daejeon, Korea
S. H. Park, Korea University Sejong Campus, Sejong, Korea
[1]also at Budker Institute of Nuclear Physics, Novosibirsk, Russia

Abstract

A new compact THz free electron laser driven by a microtron is being developed recently at KAERI. It uses a hybrid electromagnetic undulator. A novel scheme of injection/extraction/outcoupling is developed. The machine is partially assembled and commissioned. Characteristic features and current state are described in the paper.

INTRODUCTION

About twenty years ago the first compact THz FEL at KAERI has been commissioned [1]. Since then a huge number of experiments using this FEL have been conducted [2, 3]. In addition, its parameters have been improved during this intensive operation. A number of user stations have been built at this machine. It operates now, but its resource is almost consumed and operation is not so stable. In this regard, a development of a new machine seems to be a good idea. Finally, technological progress over these years is significant, so a new FEL could provide much better characteristics. Thus, it was decided to develop a new FEL several years ago.

PROJECT

The basic scheme of the new FEL has been chosen similar to that of the previous one. It consists of a microtron, a beamline, and a FEL structure, as shown in Fig. 1.

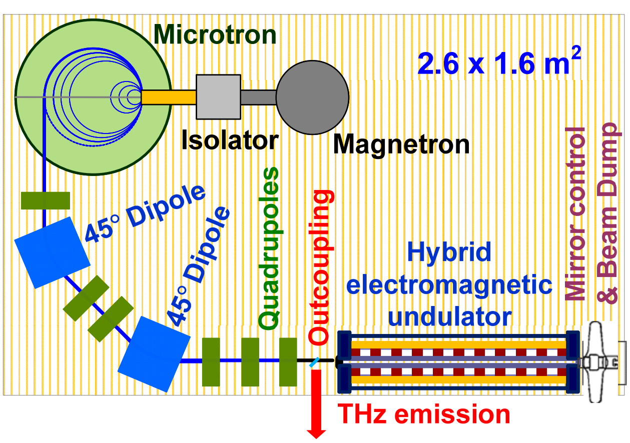

Figure 1: Schematic top view of the FEL.

The A microtron is an RF resonance electron accelerator with constant frequency and leading magnetic field, and variable harmonics number [4]. RF power is supplied by a magnetron in our case. A modulator for it is based on storage capacities, solid state switches, and a high-voltage transformer. This combination seems to be the cheapest source of a comparably high quality electron beam of the energy of several MeV. Its basic parameters in our case are as follows:

- Electron kinetic energy 4.9 MeV
- Macropulse current 40 mA
- Macropulse duration 5 μs
- Repetition rate up to 100 Hz
- Typical emittance x: 2 mm·mrad
  y: 0.1 mm·mrad
- Typical energy spread $4 \cdot 10^{-3}$

The electron beam comes further through a beamline to the FEL structure. The beamline is used for matching the beam parameters to the optimal ones for the undulator. The matter is that the beam dispersion function and its derivative are not zero at the microtron exit while both should be zero in the undulator. Also, vertical and horizontal α- and β-functions are also far enough from the optimal ones in the undulator. Thus, one should match 6 parameters, so we used the very minimum number of quadrupoles. Two dipoles (but not one) were used to make the beamline more compact and avoid too big bending angles. This beamline provides the optimal beam parameters in the undulator at all expected entrance ones and the whole range of the undulator strengths.

A hybrid electromagnetic scheme has been selected for the undulator. This device contains magnetically soft poles and both permanent magnets and coils with electric current. Its design is similar to that of the existing machine. The strength is controlled by current in the coils. The main advantage of this design over the conventional hybrid one (without coils) is absence of moving parts. It means absence of heavy loaded precision mechanics (~1 ton) and permits to fasten a waveguide of an optical resonator precisely and reliably. In addition, compensation of the 1st and 2nd integrals of magnetic field at the entrance seems to be much easier in the chosen design.

There is no horizontal focusing in a perfectly planar undulator. In this case, it is impossible to conduct an electron beam through a narrow waveguide. To compensate for this, the poles were appropriately shaped to provide significant focusing. The two utmost poles were reshaped to compensate the integrals. The basic parameters of the undulator are as follows:

† email address Miginsky@gmail.com

ISBN: 978-3-95450-179-3 doi:10.18429/JACoW-FEL2017-MOP048

- Geometry planar
- Length 1 m
- Period 25 mm
- Clearance 5.5 mm
- K 1.77…2.66
- Horizontal focusing 38…44 m^{-2}

The latter parameter belongs to the beam energy.

The peak current of the beam in our case is comparably small and the wavelength is long enough, so it is a problem to get lasing in free space. The reason is that the transverse size of the fundamental mode of an open resonator is too big, so an undulator of a reasonable period and a huge clearance is too weak and the beam-to-wave interaction is insufficient. So we chose a waveguide scheme for our FEL to reduce the mode size. The main problem in this case is wave attenuation. A lenticular shape and dielectric coating are used to solve it, as shown in Fig. 2. Some details are in [5]. In this case the power attenuation coefficient decreases by 10–17 times compared to a rectangular waveguide of similar sizes. Also the effective mode area decreases twice, so the total efficiency increases by 20–34 times. We expect the power attenuation coefficient α = 0.01…0.02 m^{-1} at λ = 0.4…0.6 mm and the effective mode area ≈ 6 mm^2, so the estimated gain $K_p - 1 \approx 2.9…4.1$. This waveguide is also much more effective than a parallel-plate one, as in the previous machine.

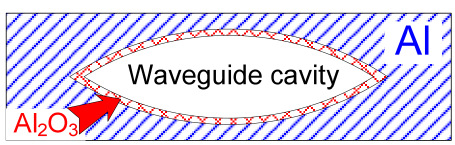

Figure 2: Cross-section of FEL waveguide.

Injection of an electron beam into and extraction from a waveguide, and emission outcoupling are interrelated and sophisticated problems. We consider combining a blind mirror of the optical resonator and a beam dump, so the extraction is not necessary. Injection and outcoupling are implemented through a mesh mirror. Another tilted mirror with a hole is necessary to separate an electron beam and THz emission, like in Fig. 3. This is possible as the THz emission divergence is significantly bigger than one of the electron beam. A mesh mirror is thin enough and does not disturb a beam significantly. For first experiments we need a mesh of 10…15% transparency in THz to ease lasing, and we should optimize it further for better efficiency.

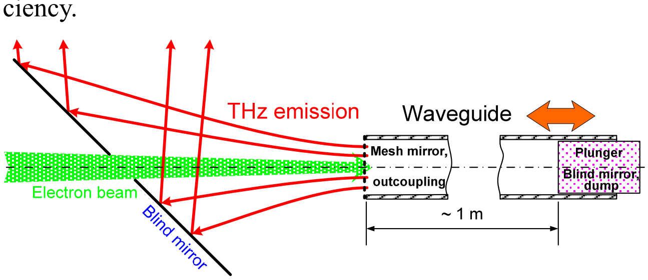

Figure 3: Outcoupling scheme.

We expect the following basic parameters of the FEL:

- Wavelength tuning range 0.4…0.6 mm
- Spectral width 1%
- Peak power 5 kW
- Macropulse average power 600 W
- Macropulse duration & repetition rate as for microtron

STATUS

At present time, the scheme and the composition of equipment for the FEL are determined. Each part has been simulated and optimized. Thus, both the conceptual and technical designs are ready. The microtron has been commissioned, and is being optimized now. Some typical signals during commissioning are presented in Fig. 4. The undulator has been manufactured and is being assembled. All the magnets for the beamline has been manufactured and tested. The following parts are to be mechanically designed and manufactured: the optical resonator, a vacuum chamber for the beamline, and supports. After that the whole machine can be assembled and commissioned.

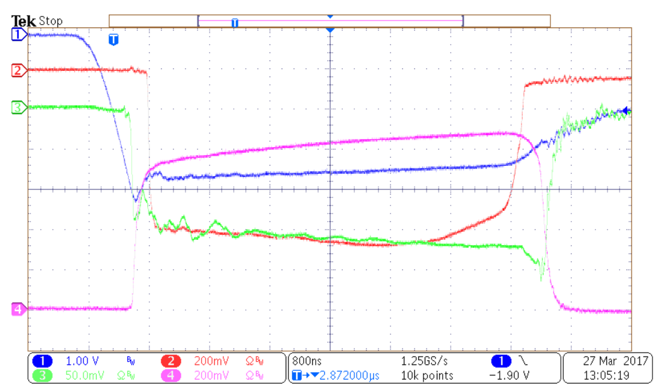

Figure 4: Microtron commissioning: (1) Modulator voltage (/1.22·10^4), (2) target current (25 Ω), (3) reflected RF power, (4) emission current (0.808 Ω).

REFERENCES

[1] Y. U. Jeong *et al.*, "First lasing of the KAERI compact far-infrared free-electron laser driven by a magnetron-based microtron", *Nucl. Instr. and Meth.*, vol. 475, pp. 47-50, Dec. 2001.

[2] Y. U. Jeong *et al.*, "Application of a wide-band compact FEL on THz imaging", *Nucl. Instr. and Meth.*, vol. 543, pp. 90-95, May 2005.

[3] Y. U. Jeong *et al.*, "Demonstration of a wide-band compact free electron laser to the THz imaging of bio samples", *Nucl. Instr. and Meth.*, vol. 575, pp. 58-62, May 2007.

[4] S. P. Kapitza and V. N. Melekhin, *The Microtron*, London, UK: Harwood Academic Publishers Ltd., 1978.

[5] S. Miginsky *et al.*, "HE$_{11}$ mode in a waveguide THz FEL", *Bulletin of the Russian Academy of Sciences. Physics,*, vol. 79, no. 1, pp. 31-35, Jan. 2015.