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# STATUS OF CAEP THz FREE ELECTRON LASER OSCILLATOR *

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*Abstract*

China Academy of Engineering Physics tera-hertz free electron laser (CAEP THz FEL, CTFEL) is the first THz FEL oscillator in China, which was jointly built by CAEP, Peking university and Tsinghua university. The stimulated saturation of the CTFEL was reached in August, 2017. This THz FEL facility consists of a GaAs photocathode high-voltage DC gun, a superconducting RF linac, a planar undulator and a quasi-concentric optical resonator. The terahertz laser's frequency is continuous adjustable from 2 THz to 3 THz. The average power is more than 10 W and the micro-pulse power is more than 0.1 MW.

## INTRODUCTION

Free electron laser (FEL) can be the most powerful tool as tera-hertz power source. It has many advantages, such as monochrome, high-power, linear-polarization, continuously-tunable frequency. A lot of FEL facilities, such as ELBE in Germany [1], FELIX in Holland [2], UCSB in the USA [3] and NovoFEL in Russia [4], have played important roles in the THz sciences. In the near future, of the 20 FEL facilities planned to be built in the whole world, there will be at least 8 ones operating in the THz range [5].

CAEP THz FEL (CTFEL) facility is the first high average THz source based on FEL in China [6, 7], which is driven by a DC gun with a GaAs photocathode [8, 9] and two 4-cell 1.3 GHz super-conducting radio frequency (SRF) accelerator [10]. The repetition of CTFEL is 54.167 MHz, one in twenty-fourth of 1.3 GHz. The effective accelerator field gradient is about 10 MV/m. The terahertz wave frequency is continuous adjustable from 2 THz to 3 THz. The average power is more than 10 W and the micro-pulse power is more than 0.1 MW. This paper gives an introduction of this facility and its THz laser characters.

## FACILITY COMPONENTS

### *Overview*

Figure 1 shows the layout of the CTFEL facility. High average power high-brightness electron beam emits from the high-voltage DC gun equipped with a GaAs photocathode. The beam is then accelerated by a 2×4-cell RF superconducting accelerator and gain a kinetic energy from 6 MeV to 8 MeV. Passing through an achromatic section, the beam then goes into the undulator magnet field and generate the spontaneous radiation. The radiation resonates in the THz optical cavity and reaches saturations.

Table 1 gives more information of the electron beam. The accelerator is designed to operate in both CW and macro-pulse mode. It is now working in macro-pulse mode in the first step. The typical output in this "step one" is in 1 ms and 1Hz macro-pulse mode. The duty cycle will update to >10% in 2018 as the "step two". And the CW operation will be reached in the "step three".

Table 1: Electron Beam Parameters

| Parameters | Designed value | Unit |
|---|---|---|
| Bunch charge | 10~100 | pC |
| Micro-pulse repetition | 54.167 | MHz |
| Macro-pulse repetition | 1~20 | Hz |
| Duty cycle | $10^{-5}$ ~1 | |
| Kinetic energy | 6~8 | MeV |
| Normalized emittance | <10 | $\mu$m |
| Micropulse length | 4~8 | ps |
| Energy spread | <0.75 | % |

### *High-voltage DC Electron Source*

Figure 2 shows the system of the high-voltage DC electron source, which consists of a photocathode preparation chamber, a load-lock system, a drive laser, a high-voltage DC gun and some beam elements such as three solenoids and an RF buncher. The electron source can provide 320 keV high brightness beams both in CW mode and in macro-pulse mode. The average current has reached 1 mA 5 mA. The micro-pulse length is compressed to 8 ps by the RF buncher.

### *RF Superconducting Accelerator*

Owing to the advantages of superconducting RF technology in CW mode operation, a 2×4-cell superconducting linac module has been adopted to accelerate 320 keV, 1~5 mA electron beams from the DC-gun up to an energy of 6~8 MeV. The 2×4-cell module is composed of two SRF cavities, two power couplers, two tuners and a cryostat, as shown in Fig. 3. With the goal of 5 mA, 54.17 MHz CW beams, the components have been designed accounting for higher-order modes (HOMs), beam loading and cryogenic issues. The phase stability of the low-level RF control system is 0.1°, and the amplitude stability is better than 0.05%. After the acceleration, the normalized emittance of the beam is less than 8 mm·mrad, and the relative energy spread is less than 0.2%.

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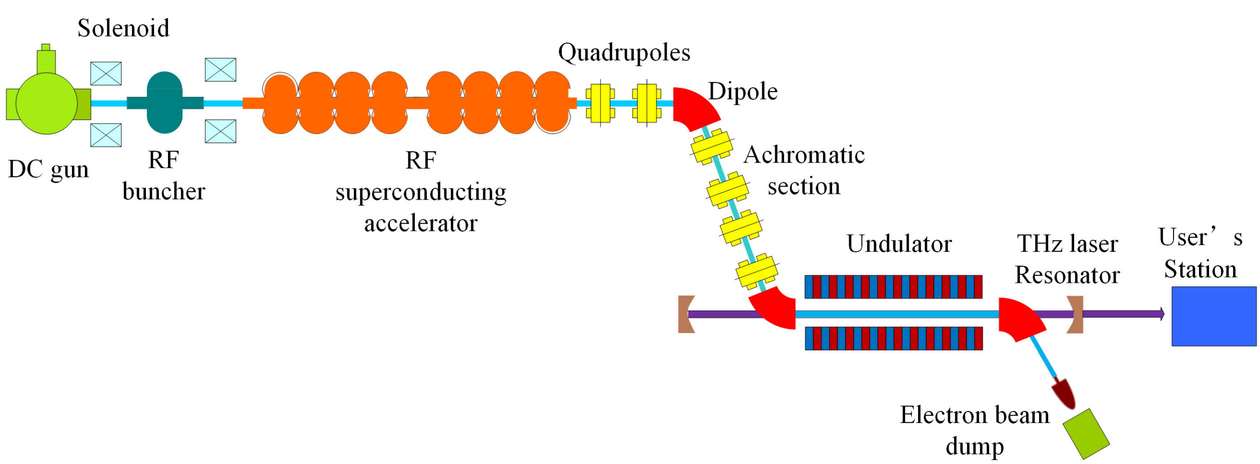


Figure 1: The layout of the CTFEL facility.

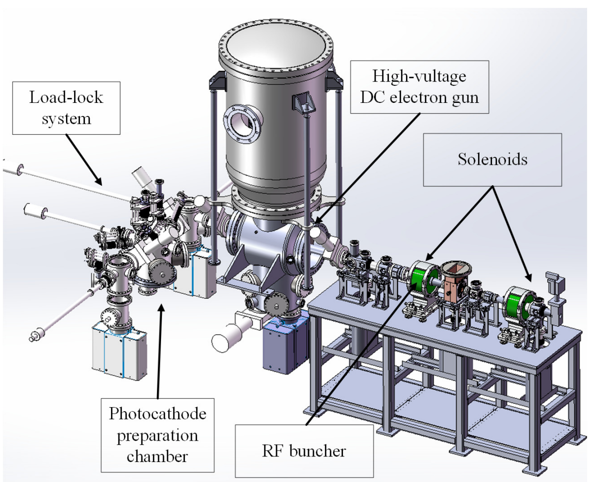


Figure 2: The high-voltage DC electron source.

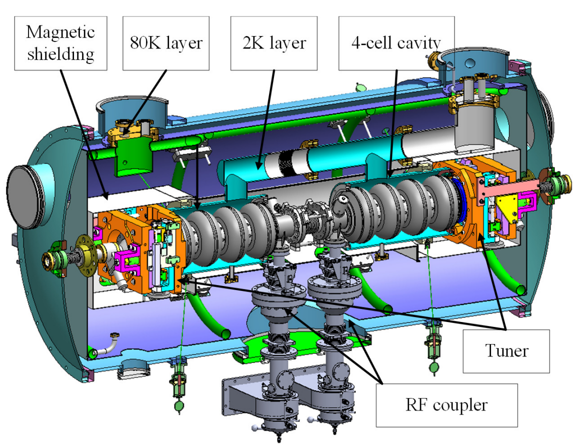


Figure 3: The RF superconducting accelerator.

### *Undulator and THz Resonator*

The THz wave is generated and resonates in the undulator and THz optical cavity system, as shown in Fig. 4. The electron beam and the THz wave fly through a THz waveguide together. The wave guide is under the undulator magnetic field. The undulator has a period of $\lambda_u$=38 mm. And the field $B_0$ is tunable from 0.2 T to 0.55 T.

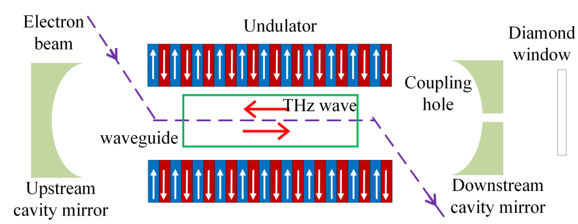


Figure 4: The undulator and the THz optical cavity.

The THz wave is reflected back and forth between the two cavity mirrors. The two mirrors form a quasi-concentric optical resonator. The terahertz laser power is then extracted by a hole of a few millimeters in the downstream mirror, and then goes through a diamond window to transmit to the user's lab.

## THz LASER PARAMETERS

Table 2 shows the main parameters in the "step one" of the THz laser downstream the coupling hole.

Table 2: THz Laser Parameters

| Parameters | Value | Unit |
|---|---|---|
| Tunable frequency range | 1.87~3.3 | THz |
| Spectral FWHM | ~2 | % |
| Macro-pulse average power | >9 | W |
| Macro-pulse repetition | 1~20 | Hz |
| Macro-pulse length | 0.3~2 | ms |
| Micro-pulse RMS length | <1 | ps |
| Micro-pulse interval | 18.5 | ns |
| Micro-pulse power | >0.1 | MW |
| Minimum transverse radius | <0.5 | mm |
| Polarization | Horizontal | |

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Figure 5 shows some measurement results of the THz laser at the user's lab. Figure 5(a) is the average power measured by a TK absolute energy meter. The THz average power is given by [11]:

$$P_{avg} = \frac{V}{0.49T\tau r_{ji}}, \qquad (1)$$

where is the output voltage of the energy meter, which is about 540 mV in Fig. 5 (a). $T \approx 0.55$, which is the transmission of the TPX window. The pre-calibrated $r_{ji}$=0.233 mV$\cdot\mu$J$^{-1}$. On the bottom of the formula, 0.49 means that the absorption of the energy meter's metal film is about 49%. And 950 $\mu$s, which is the macro-pulse length measured by a GeGa detector, as shown in Fig. 5 (b). All the results indicate the macro-pulse average power is about 9 W. Therefore, the THz transmission does not lose too much power.

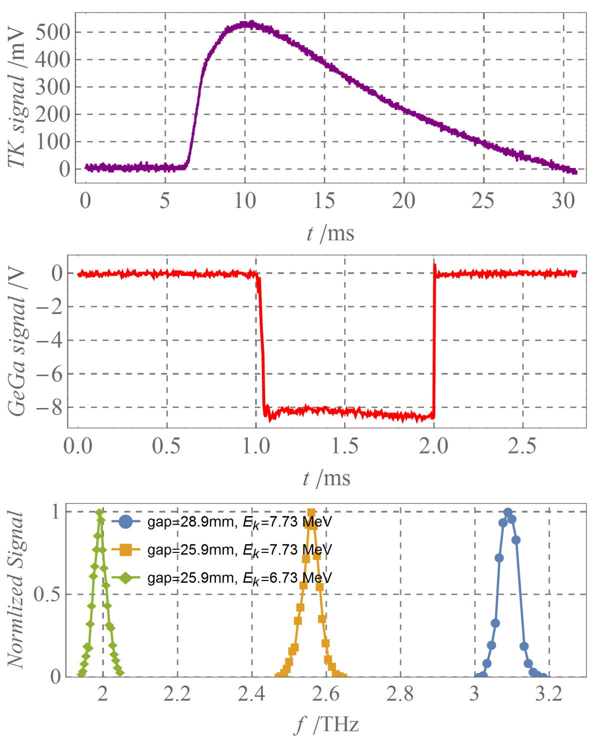


Figure 5: The THz power and frequency measurement.

The spectrum at three single spots is shown in Fig. 5 (c), which is measured by a grating spectrometer. The frequency is adjusted by both the undulator gap and the electron energy. The spectral FWHM is a little wider than theoretical simulation because the micro-pulse length is a little shorter, typically as short as about 400 fs (RMS), making the peak power more than 0.1 MW.

## SUMMARY

This paper has briefly introduced the CTFEL facility, which is the first THz free electron laser oscillator in China. This facility mainly consists of a high-brightness high-voltage DC electron source, a CW RF superconducting accelerator and an undulator-optical-cavity system. The CTFEL facility provide monochrome, high-power, linear-polarization, and frequency-continuously-tunable THz laser. The terahertz frequency is continuous adjustable from 2 THz to 3 THz. The average power is more than 9 W and the micro-pulse power is more than 0.5 MW. This facility will greatly promote the develop-ment of the THz science and its applications on material science, chemistry science, biomedical science and many other cutting-edge areas in general.

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