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FIRST LASING AT THE CAEP THz FEL FACILITY*

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Abstract

China Academy of Engineering Physics terahertz free electron laser (CAEP THz FEL, CTFEL) is the first THz FEL user facility in China, which was an oscillator type FEL. 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 0.7 THz to 4.2 THz. The average power is more than 10 W and the micro-pulse power is more than 0.3 MW. In this paper, the specific parameters and operation status of CTFEL are presented. Finally, some user experiments are introduced briefly.

INTRODUCTION

Terahertz (THz) radiation is an electromagnetic wave with a frequency range of 0.1 to 10 THz. It is between microwave and infrared light and has very unique properties such as transient, low energy, penetration, and broadband. It has caused widespread concern in recent years. Free electron laser (FEL) can be the most powerful tool as terahertz power source. It has many advantages, such as monochrome, high-power, linear-polarization, continuously tunable frequency. Many 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) is the first THz FEL user facility in China [6, 7], which is an oscillator type FEL, see Figure 1. This THz FEL facility consists of a GaAs photocathode high-voltage DC gun, a 1.3 GHz superconducting RF linac [8, 9], a planar undulator and a quasi-concentric optical resonator. The repetition of CTFEL is 54.167 MHz, which means the average current can be up to 5 mA. The effective accelerator field gradient is about 10 MV/m.

CTFEL has achieved the saturation radiation in August, 2017[10] after two year's commissioning. The terahertz wave frequency is now continuously adjustable from 0.7 THz to 4.2 THz. The average power is above 10 W and the micro-pulse power is more than 0.5 MW. In this paper, the components of this facility and some of its applications are introduced. Also an upgrade plan is proposed.

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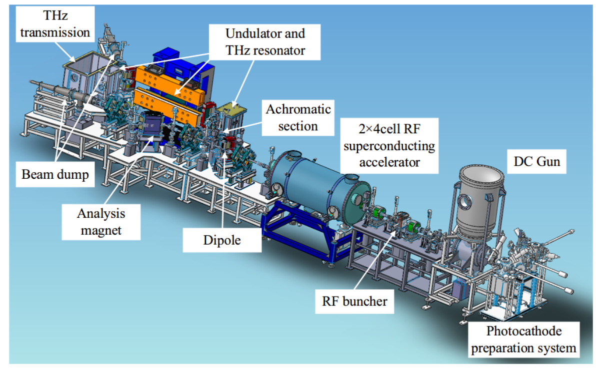

Figure 1: The Layout of the CTFEL Facility.

FACILITY COMPONENTS

Overview

Figure 2 shows the block diagram of the CTFEL facility, in which you can see more details. The 532nm continuous mode-locked driving laser is incident on the photocathode of the gallium arsenide semiconductor. The electrons are laterally focused by a solenoid, longitudinally bunched through the buncher, then enters the superconducting cavity, where electrons are finally accelerated to 7~8 MeV. The accelerated electrons are transported through the achromatic section into the undulator to generate THz spontaneous radiation. The radiation resonates in the THz optical cavity and reaches saturation. Saturated THz light is coupled out through the small hole in downstream mirror, and the output terahertz light is transmitted to the user's laboratory for user experiments.

The electron beam parameters are summarized in Table 1. The accelerator is designed to operate in both CW and macro-pulse mode. It is now working in macro-pulse mode with the duty cycle >10%. In the near future, the CW operation will be reached after the machine fast protection system is installed.

Table 1: Electron Beam Parameters

Parameters	Design goal	Unit
Bunch charge	10~100	pC
Micro-pulse repetition	54.167	MHz
Macro-pulse repetition	1~20	Hz
Duty cycle	10^{-5} ~1	
Average current	1~5	mA
Kinetic energy	6~8	MeV
Normalized emittance	<8	μm
Micropulse length (RMS)	1.5~ 3	ps
Energy spread	~ 0.2	%

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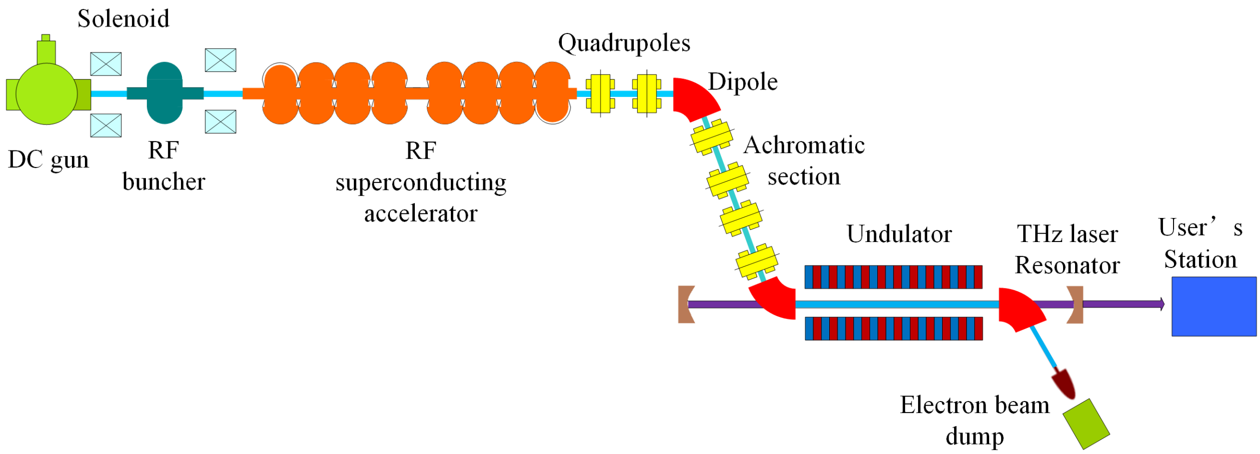

Figure 2: Block diagram of the CTFEL facility.

High-Voltage DC Electron Source

Figure 3 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 DC gun has a four-way type with a radial dimension of Φ500 mm to reduce the field strength of the electrode surface. The high-voltage insulator uses a charge-discharge-type ceramic insulator to improve the stability of the working field. The cathode support rod and the ground potential are added. By a series of technical improvement such as baking and NEG, the vacuum in the working state can be maintained at 3×10^{-9}Pa, and the electron beam kinetic energy at the exit of the electron gun is about 200~350 keV, which is currently working at 320 keV.

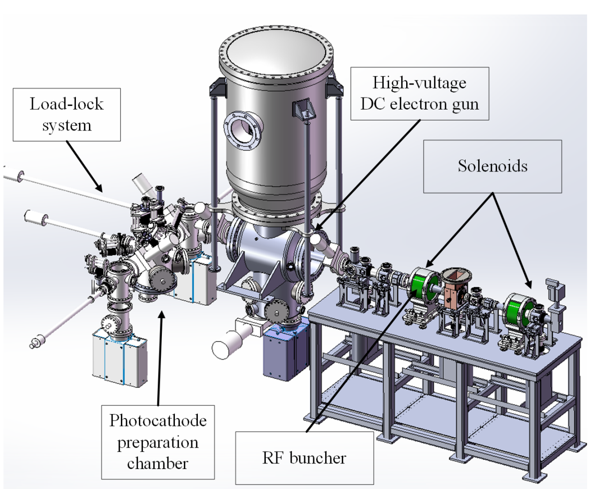

Figure 3: The high-voltage DC electron source.

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 electron beams from the DC-gun up to an energy of 6~8 MeV. 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%.

THz Resonator and Transmission

The THz wave is generated and resonates in the undulator and the THz optical cavity system. The two cavity mirrors form a quasi-concentric optical resonator with a Cavity length 2.769 m and a Mirror curvature 1.85 m. The Waveguide between optical cavity has a size of 14mm×28 mm. The terahertz laser power is then extracted by a hole of 2.4 mm in diameter on the downstream mirror, and then goes through a diamond window to transmit to the user's lab. The THz transmission system is shown in Figure 4.

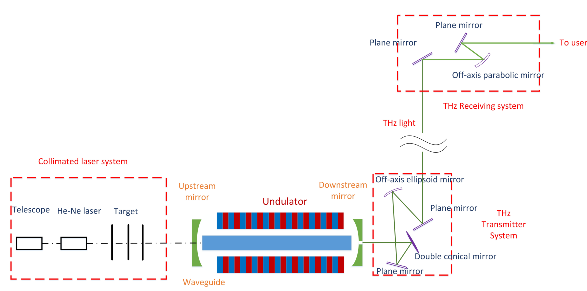

Figure 4: The THz resonator and Transmission system.

THz LASER

Table 2 shows the main parameters of the CTFEL THz laser measured in user lab. CTFEL Terahertz average power is measured by a TK absolute energy meter. The spectrum is measured by a Fourier spectrometer (Bruker VERTEX 80V), see Figure 5, also the micro-pulse length. The frequency is adjusted by both the undulator gap and the electron

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energy. The THz beam transverse profile is captured by a pyroelectric array camera "Pyrocam IIIHR“. The beam fulfill the transverse Gaussian distribution. The minimum beam size around the focal point is estimated as less than 1 mm in radius.

Table 2: THz Laser Parameters

Parameters	Value	Unit
Tunable frequency range	0.7~4.2	THz
Spectral FWHM	2~3	%
Macro-pulse average power	>10	W
Macro-pulse repetition	1~20	Hz
Macro-pulse length	0.3~2	ms
Micro-pulse RMS length	400~500	fs
Micro-pulse interval	18.5	ns
Micro-pulse power	>0.3	MW
Minimum transverse radius	<1	mm
Polarization	Horizontal	

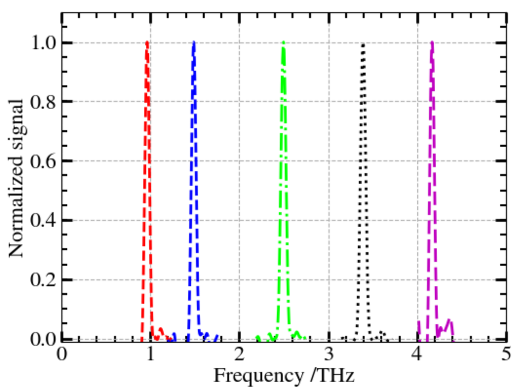

Figure 5: The THz frequency measurement.

After the completion of CTFEL, it played an important role in the field of terahertz in China. Several user experiments have been carried out on the CTFEL device. The optical rotation of molybdenum disulfide MoS_2 was studied. The optical rotation effect of single-layer MoS_2 on linearly polarized THz light was observed for the first time. The "picosecond THz pump-picosecond detection" platform was built to obtain the nonlinear THz dynamics of the GaSb sample. The graphene THz detector and the GaN detector were calibrated, by which the micropulse of CTFEL was detected. The decomposition reaction of pyrophosphate (PPi) catalyzed by alkaline phosphatase was studied, and the effect of "activation" on the enzyme was observed. The effects of terahertz on bacterial growth and physiological status of mice were studied. It was found that the growth of E. coli was affected and the protein expression level changed.

UPGRADE PLAN

Although CTFEL has played a great role in terahertz science, its frequency band is still not too wild to meet the needs of scientific research. An upgrade plan is proposed, showing in Figure 6. After the upgrade, the electron beam energy will be up to 50MeV, and the radiation frequency will be 0.1THz~150THz, covering the entire terahertz and infrared bands.In the mean time the ERL technology is applied in this project, which will increase the efficiency of the entire device. CTFEL will become an important high average power long-wavelength FEL source in the world in the near future.

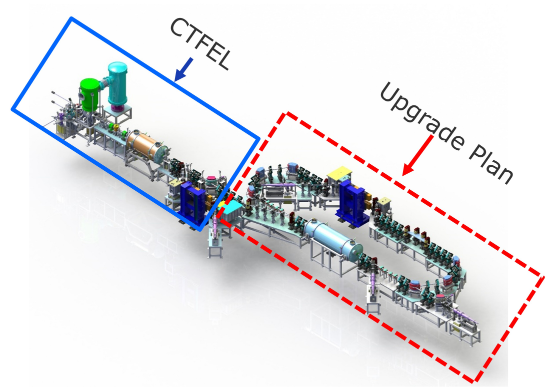

Figure 6: CTFEL upgrade plan.

SUMMARY

In this paper CTFEL facility has briefly introduced, 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 a undulator-optical-cavity system. The terahertz frequency of CTFEL is continuously adjustable from 0.7 THz to 4.2 THz. The average power is more than 10 W and the micro-pulse power is above 0.3 MW. CTFEL is an user facility, and will be upgraded in the near future, which will greatly promote the development of the THz science and its applications on material science, chemistry science, biomedical science and many other Frontier science in general.

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