THz spatial power distribution from the femtosecond linac-undulator system at SINAP

LIN Xuling[1,2,*] ZHANG Jianbing[1] BEI Hua[1,2] LUO Feng[1,2] DAI Zhimin[1,2]

[1] *Shanghai Institute of Applied Physics, Chinese Academy of Sciences, Shanghai 201800, China)*

[2] *Graduate University of Chinese Academy of Sciences, Beijing 100049, China*

Abstract The generation and observation of coherent THz undulator radiation from femtosecond electron bunches in Shanghai Institute of Applied Physics Femtosecond Accelerator device is reported. In this paper the experiment setup and first result of spatial distribution of power radiation are given.

Key words Femtosecond linear accelerator, THz, Undulator, Spatial distribution

1 Introduction

High-power, coherent and polarized far-infrared rays (FIR) can be derived from relativistic femto second electron bunches passing through a magnetic undulator. This provides a reliable and easily tunable source of THz radiations for various scientific applications, such as pump-probe studies of surfaces, liquids, and solids; and studies on high-Tc superconductors, biophysics, plasma diagnostics, and excitation of Rydberg atoms[1,2]. The analysis of coherent FIR emitted was first discussed by Motz[3]. Theoretical[4–6] and experimental[7–9] investigation of this radiation have been carried out by several groups.

A new type of coherent THz source was built at Shanghai Institute of Applied Physics (SINAP) on the fs linac, which provides electron bunches in energy of 20–30 MeV and length of 100–300 fs. The undulator, designed with the same structure of the Apple-II undulator, is elliptically polarized and tunable. Experiments aiming at characterizing the undulator and obtaining the light parameters have been done, and coherent THz radiations have been observed recently. In this paper, we describe the experiment setup and results of spatial distribution of power radiation.

2 Experimental

2.1 Theoretical background

The wavelength of the undulator radiation can be calculated by Eq.(1),

$$\lambda_1 = \lambda_U(1+ K^2/2 + \gamma^2\theta)/(2\gamma^2)$$
$$K = eB_0\lambda_U/(2\pi m_e c^2) \quad (1)$$

where γ is the electron energy normalized to the static energy of $m_e c^2$, λ_U is the undulator period and θ is the observation angle, B_0 is the peak magnetic field of the undulator, and K is called the undulator parameter.

If the wavelength of the radiation is shorter than the electron bunch length, phases of the radiation emitted by the electrons will be different from each other, i.e. the radiation is incoherent. When the wavelength is longer than the bunch length, the radiation is coherent and intensity of the radiation is proportional to the square of the electron numbers per bunch. With 10^8 to 10^{10} electrons per bunch, the radiation intensity is enhanced by that same large factor over incoherent radiation.

2.2 Accelerator system

The experiments were performed at the femtosecond accelerator in the THz Research Centre of SINAP. The

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* Corresponding author. *E-mail address:* linxuling@sinap.ac.cn

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system consists of mainly a thermionic RF gun, an α magnet, and an accelerating tube of the SLAC type. The α magnet is used to compress the bunches produced by the thermionic RF gun. The electrons are accelerated to 20–30 MeV beam bunches by the linac. The system layout is shown in Fig.1, and the design parameters of electron beam and coherent THz radiation are listed in Tables 1 and 2.

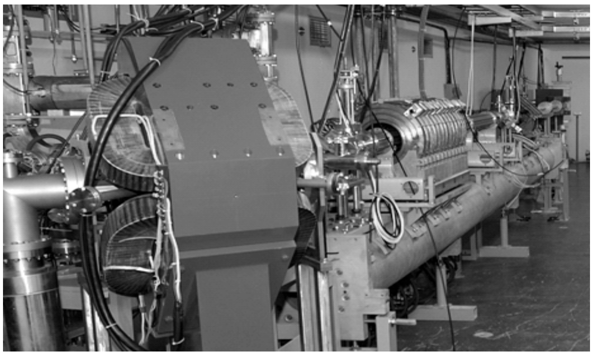

Fig.1 Layout of the fs linac.

Table 1 E-beam parameters of the linac.

Beam parameters	Values
Beam energy / MeV	20–30
Beam charge / nC	0.068
Normalized emittance/ mm·mrad	~10π
Macro-bunch repetition frequency / Hz	3.125–12.5
Micro-bunch repetition frequency / MHz	2856
Macro-bunch duration / μs	2–3
Micro-bunch duration (FWHM) / fs	~250

Table 2 Parameters of coherent THz radiation

THz radiation parameters	Values
Frequency range / THz	0.3–3
Repetition rate / Hz	3.125–12.5
Average power / W	~1
Pulse energy / μJ	~1
Pulse duration / μs	2–3

2.3 Undulator

The undulator is an Apple-II type undulator, which corresponds to four standard Halbach-type magnet rows above and below the electron orbit plane (Fig.2), can be operated in linear, elliptical or circular modes, when the two rows at one diagonal move along the longitudinal direction[10]. The magnetic structure consists of four permanent magnet arrays[11]. The upper-front and lower-back magnet arrays can be moved independently along the longitudinal direction within a range of 60 mm. Main parameters of the undulator are given in Table 3.

Fig.2 Four magnet arrays of the undulator.

Table 3 Main parameters of the undulator

Parameters	Values
Period / mm	100
Number of periods	5
Gap (fixed) / mm	36
Vertical peak field / T	0.59
Horizontal peak field / T	0.35
Peak field at circular polarization / T	0.30
Phase shift range of two magnet rows / mm	±60
Phase of horizontal linear polarization / mm	0
Phase of vertical linear polarization / mm	±50
Phase of circular polarization / mm	±33.3
Magnet block size (width × height) / mm	40×40
Wave length of horizontal linear polarized radiation / mm	0.501
Wave length of circular polarized radiation / mm	0.269

2.4 Light transport

The light produced by the THz undulator is transported by an infrared beam line[12], which consists of two ellipsoidal mirrors that are adjustable in two angles to allow an optimization of the light transmission. Much like an ellipse mirror, all lights emitted from one focal point of an ellipsoid are focused at the other focal point. As shown in Fig.3 for the infrared beam transfer line, a *Φ*70 mm glass window is located at F1, separating the 10^{-6} Torr (1.3×10^{-4} Pa) vacuum of the linac from the air.

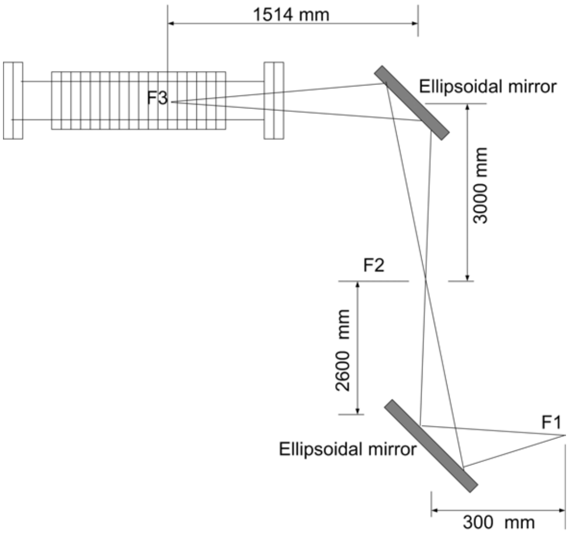

Fig.3 Sketch of the infrared beam transfer line.

2.5 Detector and test platform

A room temperature pyroelectric detector, a $LiTaO_3$ crystal of 2-mm active diameter, was used to measure the THz radiation intensity. Incident photons are absorbed by the $LiTaO_3$ crystal and converted into heat, hence the temperature increase of the crystal. The change in temperature alters the lattice spacing of the crystal. As a result, the crystal expands and generates a polarization current. The polarization current is neutralized through an external circuit with electrodes on front and back surfaces for the crystal. The output signal from the sensor is proportional to the temperature change of the crystal, and this determines intensity of the incident radiation[13]. The detector, according to the product specifications, can detect radiations in wavelengths of up to 3 mm. Compared with Golay detector, the pyroelectric detector has fast temporal response, as shown in Fig.4, obtained in our experiment.

The detector is mounted on two orthogonal translation stages that are movable under computer control. Through the computer interface under LABVIEW environment, the detector can be moved in *X* or *Z* direction in defined steps and the detector signal at each location is recorded. In the measurement, the detector moved in 2-mm steps over a 70mm×70mm scanning plane 50 mm away from the glass window (F1 in Fig.3).

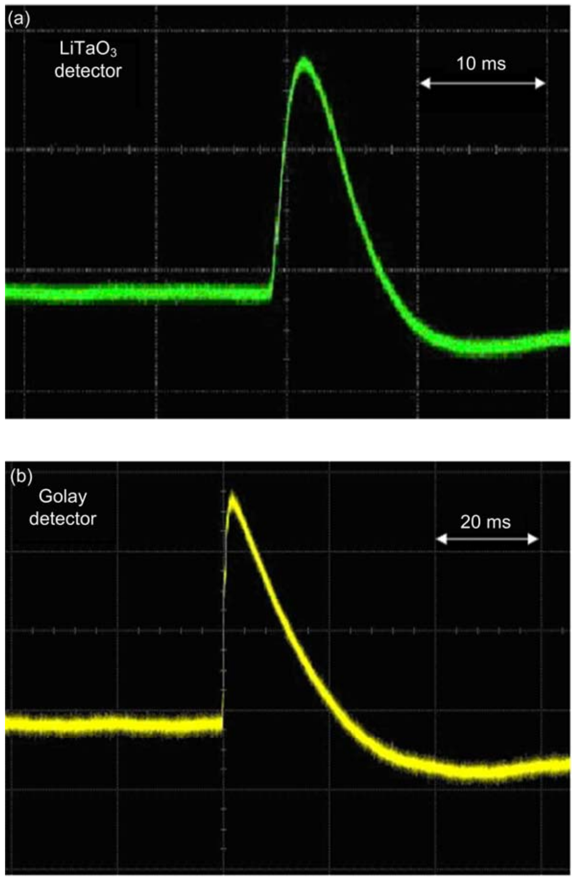

Fig.4 Signal from the pyroelectric (a) and Golay detectors (b).

3 Results and discussion

Fig.5 shows the surface plot (a) and contour plot (b) of the spatial power distribution of the undulator. The THz radiation is guided through air directly and then focused via a parabolic mirror to determine the integral power. The detector response is 150 kV/W at 5 Hz, as was calibrated with an 800 K blackbody. It is our first spatial distribution result from undulator radiation. At present, the total power measured is about 160 mW, which is lower than expected. Possible reasons accounting for this may include the followings: (1) the klystron power does not reach the designed value, (2) energy spread of the electron beam is augmented when it passes through the undulator (up to several percent of the operational energy), and (3) the glass window attenuates THz light to a certain extent. As the next steps, the klystron will be replaced with a new one, the glass window with an HDPE (high density polyethylene) window, and operation parameters of the system will be optimized.

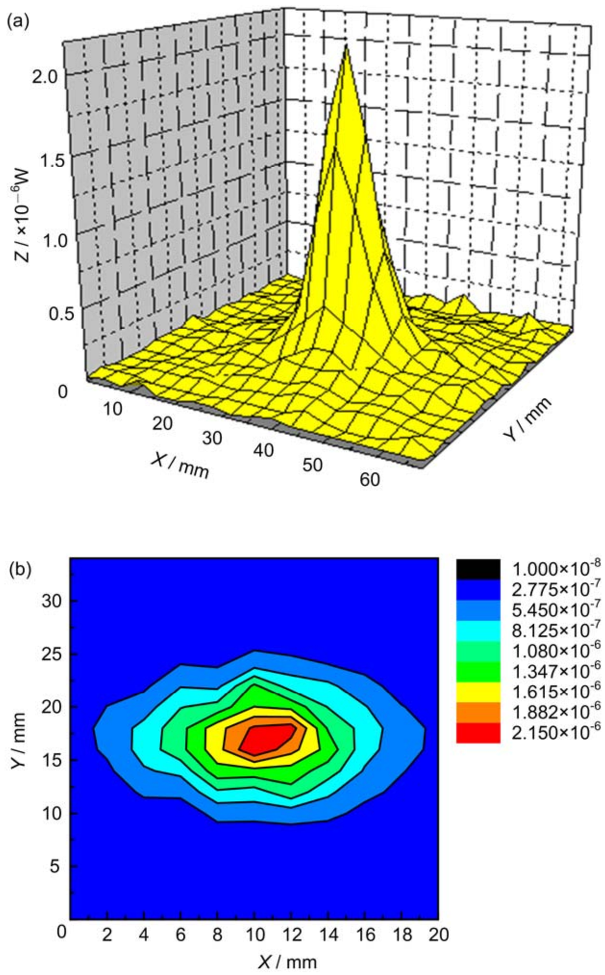

Fig.5 Surface plot (a) and contour plot (b) of the spatial power distribution 50 mm away from the glass window.

4 Conclusion

Coherent THz undulator radiation from femtosecond electron bunches has been observed on the femtosecond accelerator at SINAP. Experiment was performed to measure spatial power distribution of the radiation from the undulator. Further steps towards improving the femtosecond linac-undulator system and optimizing its operation parameters are under way.

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