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High power wideband terahertz sources based on femtosecond facility

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Abstract: The THz radiation generated by the vacuum electron device is often the ring-based or linac-based source. The generation of relativistic, sub-picosecond electron pulses allows the direct production of high-power, coherent THz radiation by passing the electron beam through an undulator. This provides a reliable and easily tunable powerful source of THz radiation for scientific applications. In this paper, the generation and observation of coherent THz undulator radiation from a femtosecond accelerator facility was reported. The accelerator facility consisted of an S-band thermionic cathode RF-gun, an alpha magnet and a SLAC-type accelerating tube, which could provide the electron bunches with energy of 20–30 MeV and bunch length of 100–300 fs. The undulator was an Apple-II type undulator, which could operate in various linear, elliptical or circular modes when the two rows at one diagonal moved along the longitudinal direction. To measure the frequency spectrum of the THz radiation, a modified Michelson interferometer was employed. The experiment setups were described and experiment results were given.

Key words: THz;　high power;　wideband;　undulator

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采用飞秒装置的高功率宽带太赫兹源

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摘　要：真空电子器件产生的THz辐射通常是基于环形或直线型的加速器装置。飞秒级的电子束团通过周期性的磁铁可产生高功率、宽带可调谐的相干太赫兹辐射。这种高功率的太赫兹源为太赫兹技术的应用研究提供了新的手段。介绍了一种基于飞秒直线加速器装置产生的相干太赫兹波荡器辐射源，它主要由S波段热阴极微波电子枪，α磁铁和SLAC型加速管组成，该装置能够提供具有20~30 MeV能量、束团长度为100~300 fs的电子束团。波荡器采用的是Apple-II型波荡器，通过调节波荡器两平行磁块的位置可以产生具有不同极化特性的太赫兹辐射。为了测量波荡器产生的相干THz辐射谱，采用改进型的迈克尔逊干涉仪来进行测量，给出了实验装置的介绍以及实验结果。

关键词：太赫兹；　高功率；　宽带；　波荡器

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0 Introduction

The terahertz radiation is frequently treated as the spectral region within frequency range $\nu \approx 0.1-10$ THz ($\lambda \approx 3\,000-30$ μm), which lies in the gap between microwaves and infrared. This so-called 'terahertz gap' has historically been defined by the relative lack of convenient and inexpensive sources, detectors and systems for terahertz waves. THz radiation has several remarkable advantages for imaging compared with other conventional sources, such as safe energy range without ionization to the materials, foot print spectral region of most chemicals and bio-materials, and relatively high spatial resolution for bio-medical imaging [1-5]. However, there are still several technical obstacles that prevent the application of the THz radiation to the practical imaging at clinics and laboratories. One of the most serious and difficult problems is the huge absorption of the THz radiation in liquid state of water. Penetration depth of the THz radiation to human tissue is limited up to a few millimetres because of the water in the tissue. To increase the depth, it is necessary to develop much sensitive way of the THz detection, and high-power THz sources as well. In this paper, a high power THz source is introduced which is produced by femtosecond linear accelerator.

1 Experiment setup

The high power coherent THz source was built in the THz Research Centre of Shanghai Institute of Applied Physics (SINAP), which consists of an S-band thermionic cathode RF-gun, an alpha magnet and a SLAC-type accelerating tube. The alpha-magnet is used to compress the electron beam from few tens of ps to few hundreds of fs in length. A SLAC-type accelerating tube is used to accelerate the electron beam up to high energy to minimize the lengthening force in the drift space.

1.1 Principle of operation

Phase coherence in radiation, such as occurring from bunches shorter than the radiated wavelength, leads to an increase in radiated energy as given by the form factor[6]:

$$f(k)=\left|\frac{1}{N_{\mathrm{e}}}\sum_{j=1}^{N_{\mathrm{e}}}\mathrm{e}^{\mathrm{i}kz_j}\right|^2$$

Where the z_j is the longitudinal position of the particles and N_e is the total number of particles in the bunch. Then the coherent energy is

$$E_{\mathrm{coh}}(k)=N_{\mathrm{e}}^2 f(k)E_{1\mathrm{e}}(k)$$

Where $E_{1\mathrm{e}}(k)$ is the energy radiated by a single particle. The total energy radiated by a single electron of energy $\gamma=E/mc^2$ traversing an undulator is[7]:

$$E_{1\mathrm{e}}=\frac{N_u q_{\mathrm{e}}^2}{6\varepsilon_0}\frac{2\pi}{\lambda_u}K^2\gamma^2$$

where N_u is the number of undulator periods, λ_u is the period length, and K is the undulator strength parameter. Since there are 10^8-10^{10} electrons in each bunch, the radiation intensity is very powerful.

1.2 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. It can operate in various linear, elliptical or circular modes when the two rows at one diagonal move along the longitudinal direction[8]. The magnetic structure consists of four permanent magnet arrays. The upper-front and lower-back magnet arrays can be moved independently along the longitudinal direction within a range of 60 mm. The main parameters of the undulator are shown in Tab.1.

Tab.1 Main parameters of the undulator

Parameter	Value
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

1.3 Beam transport

The light produced by the THz undulator is transported into the experimental Hall by an infrared beam line. It is composed of two ellipsoidal mirrors, both of which are adjustable in two angles to allow an optimization of the transmission of the transfer line. Much like an ellipse mirror, all light beams emitted from one focal point of an ellipsoid are focused at the other focal point. A Si window of 70 mm in diameter is located at F1, separating the 10^{-6} Torr (1 Torr = 133.32 Pa) vacuum in the accelerator from the air. Sketch of the infrared beam transfer line is shown in Fig.1.

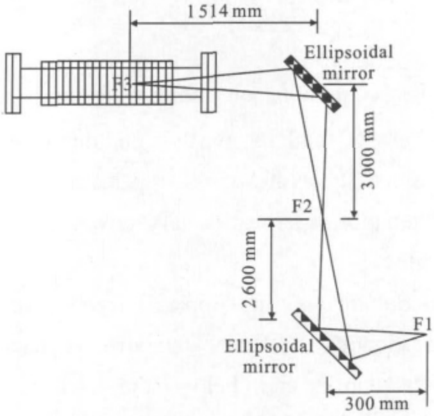

Fig.1 Sketch of the infrared beam transfer line

1.4 Measurement equipment

We use a room temperature pyroelectric detector to measure the THz radiation intensity. This detector consists of a 2 mm active diameter $LiTaO_3$ crystal. When the pyroelectric crystal is exposed to incident radiation, radiation is absorbed and converted into heat, which increases the temperature of the crystal. The change in temperature alters the lattice spacing within the crystal. As a result, the crystal expands and generates a polarization current. The polarization current is then neutralized through external circuit by electrodes attached to front and back surfaces for the $LiTaO_3$ crystal. The output signal from the sensor is therefore proportional to the change of the crystal temperature which is determined by the incident radiation. The detector was calibrated with 800 K blackbody.

The detector is mounted on two orthogonal translation stages and the movement is controlled through a computer. Though the computer interface under the LABVIEW environment, the detector can be moved in *x* or *z* direction with a selectable step size and the detector signal at each location is recorded. We detect the peak power of THz light is about 0.4 MW.

The spectral content of the coherent emission from the undulator port was measured using a step-scan modified Michelson interferometer. The measurements results are shown in Fig.2.

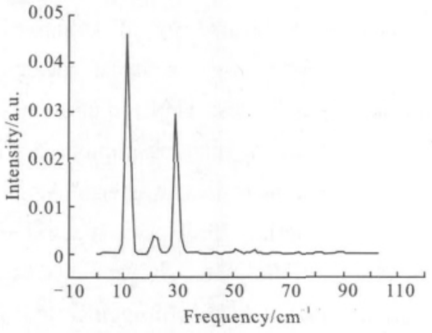

Fig.2 Measurements of coherent undulator radiation spectrum

2 Conclusion

The high power coherent undulator radiation emission from femtosecond accelerator device way observed. The coherent spectral content was measured. In the next stage, some biology and chemistry experiments will be carried out.

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