TUNABLE HIGH-POWER TERAHERTZ FREE ELECTRON LASER AMPLIFIER*

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Abstract

In this paper we present an ongoing project under the collaboration between Peking University (PKU) in Beijing and National Tsinghua University (NTHU) in Taiwan to develop tunable wavelength THz with high peak and average power from a THz free-electron laser (FEL) amplifier driven by a superconducting accelerator system at PKU and a tunable THz seed which is provided by a THz parametric amplifier (TPA). Simulation results show that narrow-band, wavelength-tunable THz radiation with 0.05-0.8 MW peak power and Watt-level average power can be expected.

INTRODUCTION

THz have attracted much interest in many undisclosed phenomena. Especially in non-invasive diagnosis, security scanning, physics study and manufacturing. THz radiation sources are developing very fast. Free-electron laser (FEL) is an important technology to generate high-power THz radiation [1]. SASE THz FEL is difficult to realize because it requires high electron bunch charge, so most of the THz FEL devices are operating in the FEL oscillator [2,3]. We would like to develop another method—seeded amplifier. We try to use THz seed and superconducting accelerator to generate THz radiation with high peak power and average power simultaneously. THz FEL amplifier was first proposed by C.Sung et al in 2006. They used a TW CO_2 laser through different frequency generation (DFG) in GaAs crystal to generate THz seed [4,5]. We will choose a more compact design to generate THz seed by optical technology—THz parametric amplifier (TPA), which can produce wavelength tunable from 1 to 6 THz and narrow-band spectrum THz. In this paper, we present FEL simulation of THz FEL amplifier and preliminary study on TPA THz seed.

SYSTEMLAYOUT

Our THz FEL amplifier system comprises two major components, the FEL amplifier and the THz seed. Figure 1 shows the configuration of the THz parametric amplifier. A pulse laser at 1064 nm and a wavelength tunable external-cavity diode laser (ECDL) pump a lithium niobate (LN) or KTiOPO4 (KTP) crystal, then generate a tunable narrow-band THz seed. Figure 2 shows the superconducting accelerator system at PKU, including the DC-SRF photoinjector which has been put into operation since 2014 and can provide 3MeV electron beam with bunch charge up to 60 pC, a SRF linac with two 1.3GHz Tesla-type cavities and a planer undulator. This superconducting system is expected to deliver high repetition rate electron beam with the energy of 8-25 MeV. It is under installation and will be operated in this autumn.

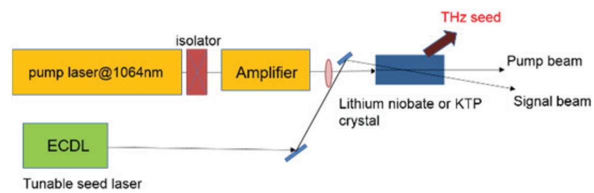

Figure 1: Configuration of the TPA THz seed system.

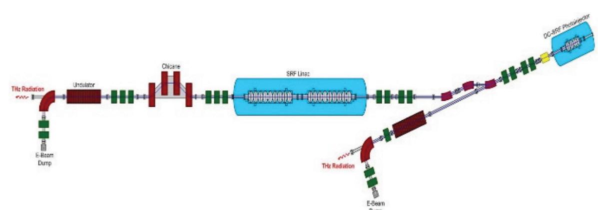

Figure 2: Superconducting accelerator system at PKU.

THz PRARMETRIC AMPLIFIER

In recent years, tunable THz-wave sources with high temporal and spatial coherence using the resonant frequency of ferroelectric crystal lattices at room temperature are popular. TPA can generate tunable coherent radiation [6]. This optical technology is based on tunable light scattering from the long wavelength side of the A1-symmetry mode in LN which has a high gain coefficient from 0.5 THz to 3 THz [7]. Molecular of crystal absorb photons of pump laser and transit to a virtual energy level. Near-infrared (NIR) photons and THz photons from the vibrational mode of molecular will be generated through Stimulated Raman Scattering (SRS) process. The frequency of THz photon equals to the difference between the frequency of pump laser and seed laser. The output NIR, which has the same frequency with the seed laser, usually used to derive the THz information. The output THz is distributed in a certain angle which

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satisfies the phase-matching condition. The TPA has been proved to be a useful coherent, narrow-band THz source which can continuously tunable in 0.5 to 3 THz at room temperature [8]. The tuning is accomplished by controlling the wavelength of signal beam. In the past several years, THz frequency has been extended to 3-6 THz by using KTP which has higher response frequency and higher damage threshold [9].

We have successfully built a TPA test system at NTHU with a 500ps mode-locked laser which can produce more than 2mJ pump laser after a side-pumped Nd:YAG amplifier. The system is shown in Fig. 3. With this system, the pumping intensity can reach a few GW/cm^2, the ECDL can operate in CW mode with 600mW output power which is tunable from 1066nm to 1082nm. Finally, we can get THz radiation with 10W peak power from LN crystal. The THz power measured by a Golay cell is shown in Fig. 4.

Figure 3: TPA test system at NTHU.

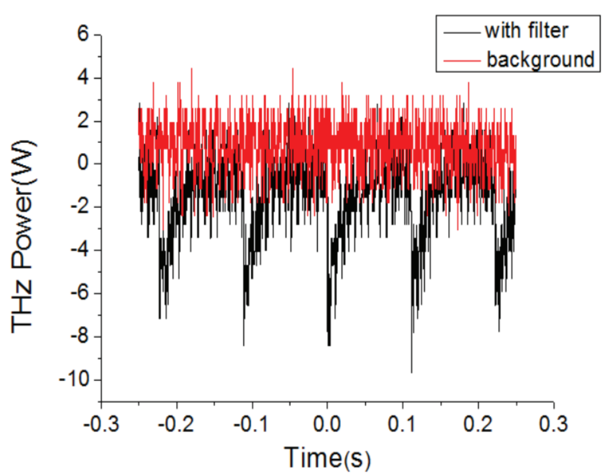

Figure 4: The measurement of THz power.

FEL SIMULATION

We use Genesis code for FEL simulation. The basic parameters of electron beam before undulator used for simulation are shown in Table1. We suppose that beam distribution is uniform in transverse and Gaussian in longitudinal.

We investigate the relationship between THz peak power and bunchlength. As shown in Fig. 5, the maximum peak power is obtained with the bunch length of 2.5 ps. Because THz wavelength is long, the slippage effect would be serious when the electron bunch is too short. On the other hand, if the beam length become longer, the peak power of THz also decreases due to the lower peak current of electron beam.

Table 1: Electron Beam Parameters for FEL Simulation

Parameter	Value	Unit
Electron beam energy	10~25	MeV
Bunch length	2.5	ps
Energy spread	0.5%	
Emittance	2	mm-mmrad
Beam size	200	μm

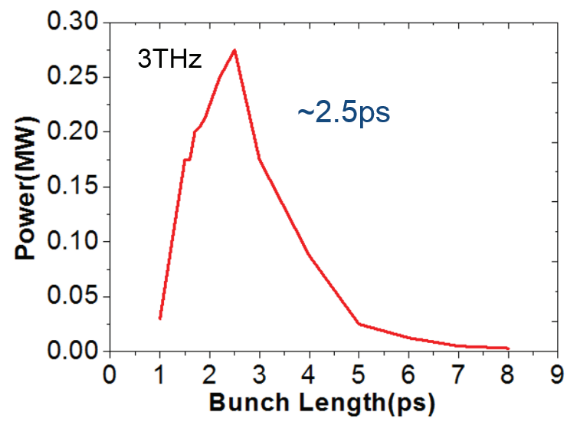

Figure 5: The relationship between THz peak power and bunch length.

We compare the gain curves along z coordinate with different power of THz seed. When the seed power is 0, it is a process of SASE. When the seed power is 1W, only 1THz FEL reaches saturation at 4m. When the seed power is increased to 10W, 2 and 3THz reach satiation at 4m. It is obvious that higher seed power is better, but it is difficult to obtain the peak power higher than 10W with TPA. We also find that THz radiation with higher frequency has higher peak power. For 4 to 6 THz, longer undulator whose length is about 4.6m is needed for saturation. Here we choose the undulator period length of 4cm, which is the same as our existed undulator. Due to the limited space, the period number is chosen to be 100.

In Fig. 6, we plot the power profiles and spectra with different frequency. The peak power is from 0.2 MW to 0.8MW when the THz frequency is from 2THz to 6THz. If we suppose the repetition rate is 1MHz, then the average power is from 0.6W to 2.4W. The product of fwhm spectral width (Δf) and pulse duration (Δt) is 0.59, close to Fourier transform limit for Gaussian distribution. That means the THz radiation has good temporal coherence.

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The THz power could be further increased by using tapered undulator. The peak power increased to from 0.25MW to 2MW at 3THz when the taper is 12% starting from 1.5m.

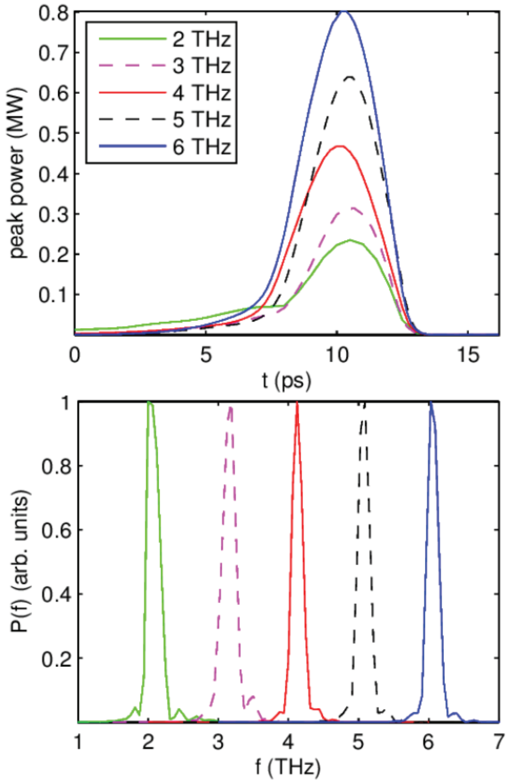

Figure 6: Power profiles and spectra with different frequency.

SUMMARY

In this paper, we present a plan of THz FEL amplifier based on TPA seed and 8~25 MeV superconducting accelerator was proposed by PKU and NTHU. On the test system of THz seed, we have obtained narrow-band, frequency tunable THz radiation with 10W peak power.

Simulation results show that THz radiation with tunable frequency from 1 to 6 THz, peak power higher than 0.8 MW and average power of several watt can be generated.

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