DESIGN STUDY ON THz SEEDED FEL USING PHOTOCATHODE RF GUN AND SHORT PERIOD UNDULATOR

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Abstract

We have proposed a compact seeded Terahertz (THz) high-gain single pass free electron laser (FEL) amplifier using a multi-bunch photocathode RF gun and a compact staggered undulator using high TC bulk superconductor[1] and injection-seeded terahertz parametric generator (IS-TPG)[2]. A design and feasibility study of the compact THz FEL amplifier have been carried out by using PARMERA[3] and GENESIS[4]. The evaluated saturation length of the THz FEL was about 1.8 m at 1.62 THz. The expected THz output power was about 30 MW.

INTRODUCTION

In the THz region, between the infrared and the microwave regions, many rotation and vibration modes of the molecule exist. Although the THz region is quite attractive, it was undeveloped until decades ago due to the lack of a compact, high-power and tunable THz source. However the recent progress of THz radiation sources and detection technique, the THz region is now called as “a new frontier”. Research community is eager to develop a compact, high-power, narrowband, tunable coherent light source in THz regime. A FEL THz source is the most powerful source in this region, and several works have been carried out to realize compact THz FEL[5 -7]. In this work, we proposed a compact seeded THz FEL amplifier using a photocathode RF gun and a novel bulk high-TC superconducting (HTSC) staggered array undulator[1] and injection-seeded terahertz parametric generator (is-TPG)[2]. A design study on the compact THz FEL amplifier was performed. To investigate feasibility of the THz FEL, a simple model which consists of a RF gun, a focusing solenoid and an undulator was used. First, the electron beam from the photocathode RF gun was optimized by changing RF electric field and laser injection phase. Then the beam profile in the bulk HTSC staggered array undulator was optimized by changing solenoid field attached to the RF gun. Finally, by using the optimized parameter, power evolution along the undulator is calculated.

DESIGN

The proposed seeded THz FEL source works as a high-gain FEL amplifier. The electron bunch with high charge (in the nC regime) from the photocathode RF gun is injected to the undulator. To obtain a higher FEL gain in a small size, a short period undulator (10 ~ 20 mm) with strong magnetic field of several Tesla is considered. A synchronized THz light generated from the same optical pulse for photocathode RF gun is injected as a seed light. A conceptual drawing of the THz FEL source is shown in fig. 1. This system has following advantages:

1. The Fourier transform limit of the THz seed pulse can overcome the disadvantage of broad spectrum of a self-amplified spontaneous emission (SASE).
2. The resonant FEL wavelength can be rapidly controlled by changing solenoid current of the bulk HTSC staggered array undulator.
3. The single pass configuration without optical cavity mirrors helps to achieve the rapid frequency tuning.

In case of the proposed configuration, the expected physical size is 2 m ×4 m.

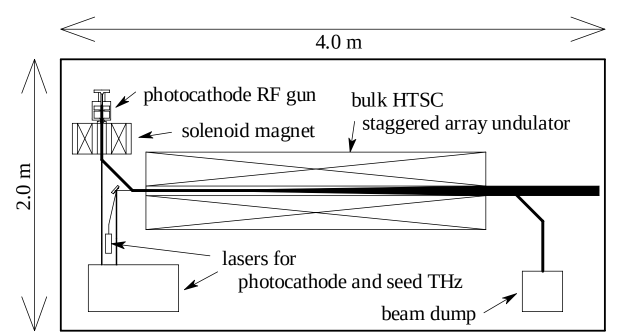

Figure 1: Conceptual drawing of the compact Table Top THz FEL amplifier. It consists of a BNL type 1.6 cell photocathode RF gun, drive lasers both for the RF gun and the THz seed light, and a bulk HTSC staggered array undulator.

Photo cathode RF gun

Recently, we planed to introduce a new photocathode RF gun in the KU-FEL MIR FEL facility to obtain an excellent electron beam[8], and fabricated the RF gun under the collaboration between KEK-ATF, AIST, Waseda Univ., and Osaka Univ. The improved BNL type 1.6-cell photocathode RF gun is expected to generate a high brightness electron beam with 1 π mm-mrad emittance and 1 nC bunch charge[9, 10].

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Bulk High TC Superconducting staggered array undulator

A transverse magnetic field in a staggered array undulator can be controlled by just changing solenoid current without mechanical structure. This advantage is quite important for rapid wavelength tuning. On the other hand, magnetic field strength is limited due to the saturation in the ferromagnetic pieces. In order to overcome the magnetic saturation, we have proposed a bulk HTSC staggered array undulator[1]. The bulk HTSC staggered array undulator consists of a solenoid and stacked arrays of bulk HTSC pieces and nonmagnetic cupper pieces. A schematic drawing of the bulk HTSC staggered array undulator is shown in fig. 2. The undulator works as following. The solenoid field is applied at above the critical temperature T_c. and then the bulk HTSC pieces are cooled down bellow T_c in the solenoid field. (Field cooling) After turning off the solenoid, the solenoid field is trapped in the bulk HTSCs and each bulk HTSC works as a magnet.

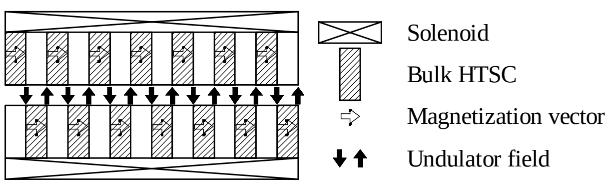

Figure 2: Schematic drawing of the bulk HTSC staggered array undulator.

Injection Seeded THz Parametric Generator

As a THz seed light, we are planning to use a injection seeded THz parametric generator (is-TPG) based on stimulated polariton scattering in a $MgO:LiNbO_3$. By controlling the wavelength of the tunable diode laser, the tunable THz can be generated. The THz output power of 1.3 nJ/pulse (peak > 200 mW) was achieved with 34.5 mJ/pulse of pump laser and 50 mW of seed laser. The wide tenability from 125 to 430 μm was obtained[2].

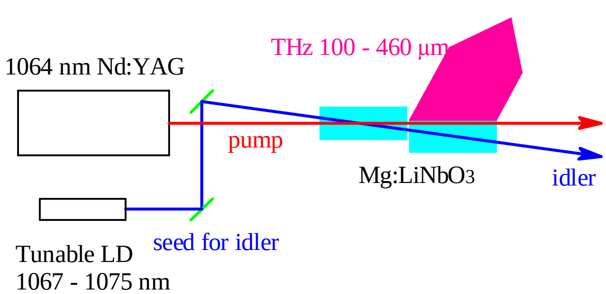

Figure 3: Principle of is-TPG THz light source.

NUMERICAL CALCULATION

To investigate feasibility of the table top THz FEL amplifier, electron beam property and the FEL power evolution was calculated by using PARMERA[3] and GENESIS[4] with a simple model which consists of the photocathode RF gun, a solenoid magnet and a bulk HTSC staggered array undulator as shown in fig. 4. In order to simplify the feasibility study, bending magnets for the laser to irradiate the photocathode and for the THz seed injection are not included. The undulator parameter used in the calculation is shown in table 1.

Table 1: Parameter for Undulator

Type	Halbach
Period length	20 mm
K value	2.0
Number of period	125

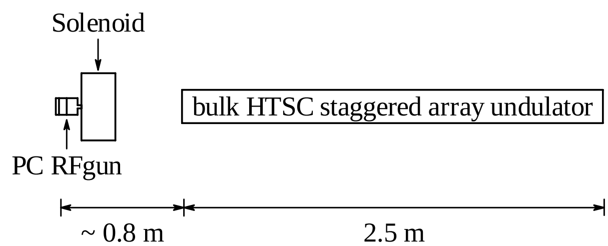

Figure 4: Layout for numerical evaluation.

Photocathode RF gun

In order to optimize the electron beam, the electric field at the cathode surface and the laser injection phase were scanned. The driver laser assumed here is a picosecond UV laser, which has a Gaussian shape profile of 0.7 mm at the cathode surface and the pulse duration of 10 ps. The scanned range of the electric field and the injection phase were set to 50 - 75 MV/m and 20 - 55 degree respectively. The beam properties (i.e. energy, energy spread, peak current and normalized emittance) at the entrance of the undulator were investigated. Results are shown in figs 5 - 8. In these calculations, the solenoid field was fixed to 2000 G.

In case of the planned is-TPG system, THz output power higher than 200 mW can be obtained between 160 and 285 μm. Thus the electron energy should be between 4.7 and 6.5 MeV for the assumed undulator which has the undulator parameter K = 2.0. Then the electric field should be between 60 and 70 MV/m as shown in fig. 5. Concerning the energy spread and the peak current, in order to obtain the higher FEL gain, the injection phase between 30 and 40 degree is preferable as shown in figs 6, 7. As shown in fig. 8, because the emittance rapidly increases as degreasing the injection phase, the injection phase should be greater than 40 degree. Accordingly, the electric field of 70 MV/m and the injection phase of 40 degree were adopted in the following evaluations.

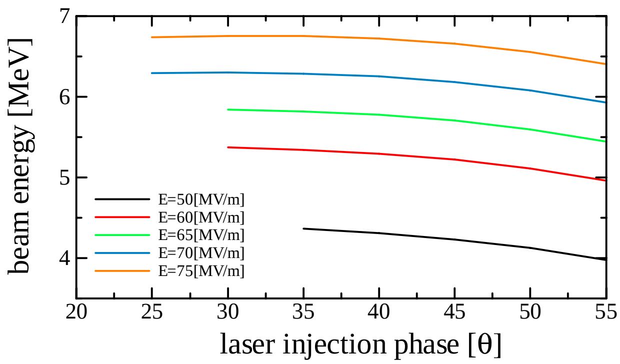

Figure 5: Beam energy at the entrance of the undulator as the function of the laser injection phase.

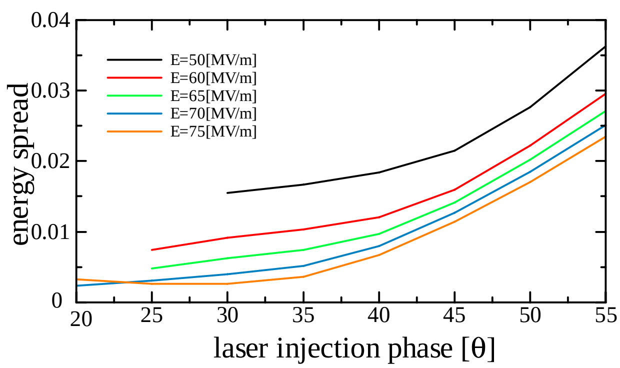

Figure 6: Energy spread.

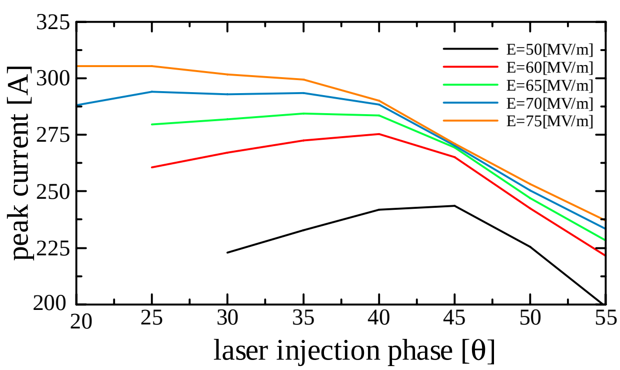

Figure 7: Peak current.

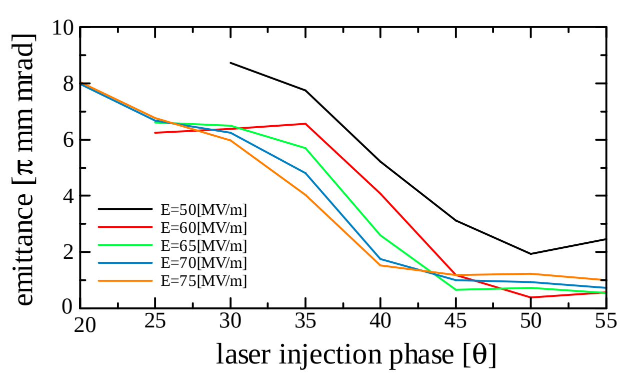

Figure 8: Emittance.

Beam focusing in the undulator

In this simple configuration, the solenoid magnet attached to the RF gun was used to control the beam focusing in the undulator. In order to improve the overlap between the electron beam and the amplified THz light, the solenoid field were optimized. The rms beam size along the beam axis for the various solenoid filed was calculated as shown in fig. 9. The evolution of the emittance was also investigated as shown in fig. 10. In comparison with the evolutions of the beam size, the dependence on the solenoid field was not strong at the entrance of the undulator. In order to minimize the average electron beam size in the undulator, the solenoid field of 2100 G was adopted. The position of the beam waist was 2.07 m from the cathode in this case, thus the entrance of the undulator was determined to 0.82 m.

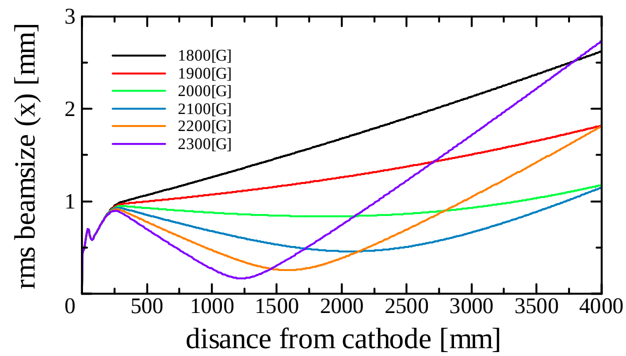

Figure 9: Evolutions of the beam size along the beam line.

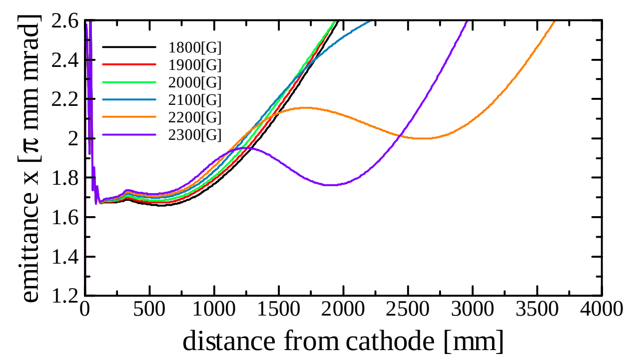

Figure 10: Evolutions of the emittance.

FEL simulation

The power evolution of the THz FEL amplifier was calculated by using GENESIS 1.3[4]. Concerning the undulator field distribution, the ideal planer undulator as same as shown in table 1 was used for the FEL simulation, because the field distribution of the bulk HTSC staggered array undulator has not been perfectly understood[1]. The optimized electron beam parameter and the conditions of the THz seed light are shown in table 2. The power evolution along the undulator is shown in fig. 11. The saturation length was estimated as 1.8 m, and the saturation power was as about 30 MW.

Table 2: Parameter for FEL Simulation

Electron beam	Energy	6.25 MeV
	Energy spread	0.8% (rms)
	Norm. emittance (x)	1.77 π mm-mrad
	Norm. emittance (y)	1.63 π mm-mrad
	Beam size (x)	0.74 mm (rms)
	Beam size(y)	0.72 mm (rms)
	Twiss parameter (x)	2.95
	Twiss parameter (y)	1.95
	Peak current	288 A
	Solenoid field	2100 Gauss
	Laser injection phase	40 degree
Seed THz	Seed power	200 mW
	Frequency	1.62 THz

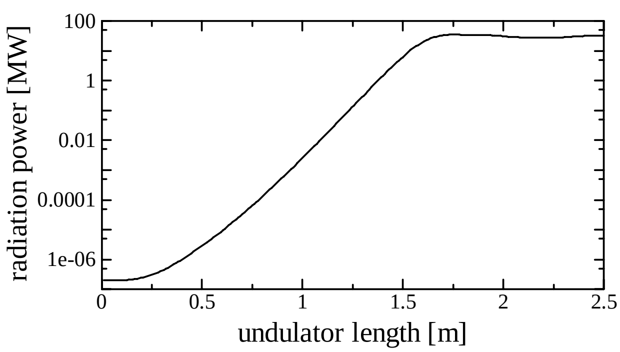

Figure 11: Growth of the FEL power.

CONCLUSION

We have proposed a compact seeded THz FEL amplifier which consists of a photo cathode RF gun, a novel bulk HTSC staggered array undulator and an injection seeded THz parametric generator. In order to evaluate feasibility of the compact Table Top THz FEL amplifier, numerical calculations have been carried out. The laser injection phase and the solenoid field were optimized to obtain higher FEL gain in the undulator. The saturation length at 1.62 THz was about 1.8 m for the optimized electron beam. The expected THz output power was about 30 MW. These results imply the possibility of a Table Top THz FEL amplifier. It should be also mentioned that the bending magnets, the effect of the diffraction loss in the long undulator, the field profile of the bulk HTSC staggered array undulator, etc. were not included in these calculation. A further approach including more realistic configuration will be continued to realize the table top THz FEL amplifier.

REFERENCES

[1] R. Kinjo, et al., In these proceedings
[2] Kawase, et al., Applied Physic Letters 80 (2002), pp. 195
[3] L.M. Young, et al., PARMELA, LA-UR-96-1835, (2001)
[4] S. Reiche, http://pbpl.physics.ucla.edu/~reiche
[5] A. Doria, et al., Nucl. Instr. and Meth. A 475 (2001), pp. 296
[6] Y.U. Jeong, et al., Nucl. Instr. and Meth. A 575 (2007), pp. 58
[7] Y. C. Huang, et al., Proceedings of APAC 2004, pp. 264
[8] H. Ohgaki, et al., Proceedings of FEL04, pp. 454
[9] R. Kuroda, et al., International Journal of Modern Physics B, vol. 21, pp.488 (2007)
[10] Y. Kamiya, et al., Proceedings of PAC07, pp. 2808