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A 3 MeV ALL OPTICAL TERAHERTZ-DRIVEN ELECTRON SOURCE AT TSINGHUA UNIVERSITY*

H. Xu[1], R. Li[1†], L. Yan[1], Y. Du[1], C. Tang[1], W. Huang[1§]
Department of Engineering Physics, Tsinghua University, Beijing, China
[1] also at Key Laboratory of Particle and Radiation Imaging, Tsinghua University, Ministry of Education, Beijing, China

Abstract

Terahertz (THz) based beam acceleration and manipulation hold great potential for table-top ultrafast electron diffraction facilities and related scientific discoveries. Many key technologies and working schemes including THz-driven electron guns, THz-driven linac and THz streaking have been successfully demonstrated, paving the way for building a real THz-based user facility. We report the physical design of an all optical THz-driven electron source aiming at delivering a 3 MeV ultrafast electron beam with tens of fC bunch charge and tens of fs bunch length, making this table-top machine suitable for general ultrafast electron diffraction experiment and related scientific research.

INTRODUCTION

Conventional accelerators have been the main approach for producing high-energy and high brightness beams until now, and we still looking for new method to improve the beam energy and brightness to new limits. Novel acceleration schemes driven by laser field [1-3], wakefield [4-6] and THz field [7-14] have showed their capabilities in generating higher field for beam acceleration and manipulation, giving us new choices for building smaller and economical facilities. THz lies between radio-frequency and optical waves, enabling higher gradient up to GV/m and can support pC level bunch charge. The mm-scale structures are easy to be fabricated with conventional machines. All optical THz accelerators share the intrinsic synchronization between THz waves and photoelectron, since they are trigged by the same seeding laser. With experimental demonstration of THz-based electron guns [7], linear acceleration [8-11], staging [12], as well as beam streaking [13-14], building a real THz-driven electron source is now essential to realize the full capability of THz-driven accelerator.

This paper reports the conceptual design of a 3 MeV THz-driven electron source at Tsinghua University. We developed a dual-feed tapered THz gun to produce a 50 keV electron beam, and boosted the beam energy to 3 MeV using a tapered dielectric load waveguide downstream. This beamline is now under construction, more results will be reported in future works.

GENERAL DESIGN

Figure 1 shows the schematic of the beamline. All the power sources and the electrons are trigged by the same seeding laser. The dual-feed THz electron gun is powered by two single cycle THz pulse, generated via optical rectification. An ultraviolet laser back-illuminated photocathode emits an electron bunch, which will be accelerated by strong THz field with an energy gain of 50 keV. A THz compressor are applied to match the beam to the main linac, where the beam energy will be boost to 3 MeV using a millijoule level multi cycle THz pulse. Another coil and THz compressor are applied to focus and compress the electron beam in the final interaction point.

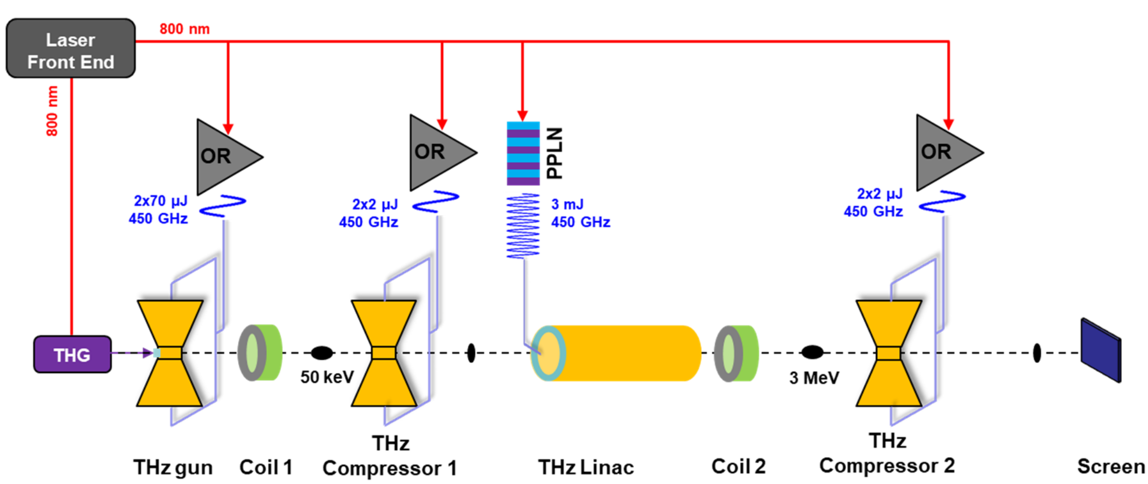

Figure 1: Schematic of the 3 MeV terahertz-driven electron source beamline.

* Work supported by Science Challenge Project (No. TZ2018005)
†lirk@tsinghua.edu.cn
§ huangwh@mail.tsinghua.edu.cn

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The THz gun is dual-feed tapered rectangular waveguide with an exponential impedance along the wave propagation direction. An exponential impedance variation is beneficial for coupling the single THz wave from free space to the interaction regime. For a given rectangular with a width of a and a height of b, the wave impedance of the TE_{10} mode at a working wavelength of λ is given as:

$$\eta_{TE10} = \frac{\eta_0}{\sqrt{1-\left(\frac{\lambda}{2a}\right)^2}} \tag{1}$$

Assuming an exponential wave impedance variation along the wave propagation direction z:

$$\eta_{TE10} = A\exp(Bz) \tag{2}$$

Where A and B are coefficients determined by the wave impedance at the entrance and the exit of the coupler. Substituting Eq. (2) to Eq. (1), the required variation of the waveguide dimension can be given by:

$$a(z) = \frac{\lambda}{2\sqrt{1+\left(\frac{\eta_0}{A\exp(Bz)}\right)^2}} \tag{3}$$

The height of the waveguide is also tapered to further improve the wave coupling. Figure 2 shows the simulated electric field distribution and beam energy. The transverse magnetic field vanishes while the electric field superposes in the acceleration regime with a field enhancement about 7.5. With two 70 μJ, 0.45 THz counter feed single cycle THz pulses, the photon electron beam is accelerated from rest to 51.8 keV with an rms energy spread about 1.5%.

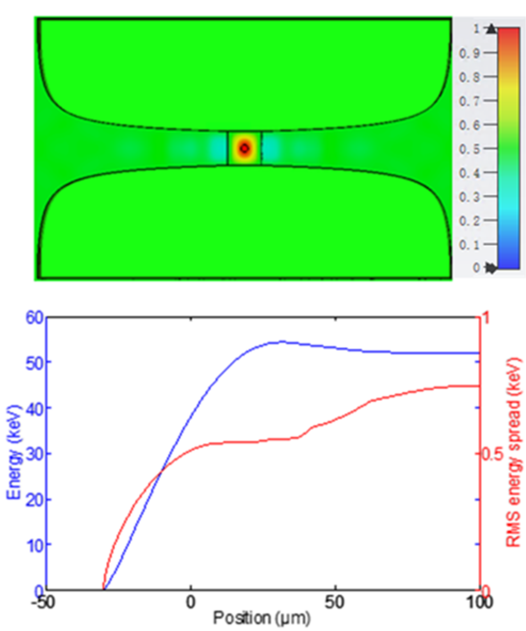

Figure 2: Simulated electric field and the beam energy.

The main linac is a tapered dielectric loaded waveguide with a constant inner diameter of 300 μm. Since the beam is nonrelativistic, the fly speed changes significantly with the energy. The dielectric thickness needs to be tapered so that the phase velocity of the THz can match the electron speed [15]. Figure 3 shows the simulated dielectric (Al_2O_3, ε=11.56) thickness and the beam energy along the beamline. With a 3 mJ, 320 ps, multi-cycle THz pulse, the bunch energy is boost from 50 keV to 3 MeV. With upgrade to the THz source power, the beam energy can be further improved by staging more subsequent linacs.

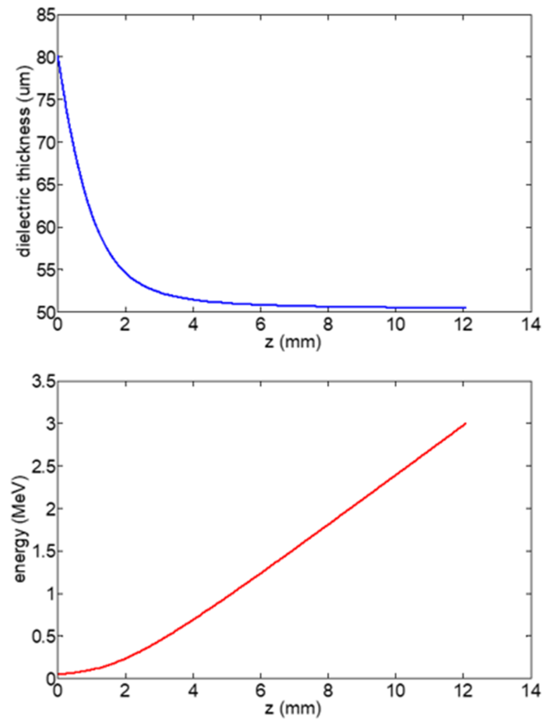

Figure 3: The dielectric thickness and the beam energy along the beam line.

CONCLUSION

We have proposed the conceptual design of an all optical THz-driven electron source at Tsinghua University. With millijoule level THz sources, the beamline hold the potential to produce a 3 MeV ultrashort electron beams, making it attractive for table-top ultrafast electron diffraction and related scientific research. The THz gun has been fabricated and is now under testing, more results will be reported in future works.

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