# THz DRIVEN ELECTRON ACCELERATION WITH A MULTILAYER STRUCTURE *

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*Abstract*

We present first results on a THz-based electron accelerator using a novel multilayer waveguide structure to utilize strong-field single-cycle THz pulses. It allows for very efficient electron acceleration using transversely-coupled short THz-waveguides with dielectric delay sections which realize phase-matching between electrons and a single-cycle THz pulse. Proof-of-concept experiments are described demonstrating 13 keV energy gain for 57 keV electron bunches from a DC-gun, which is in good agreement with simulation.

## INTRODUCTION

Over the past few years, key demonstrations have been made showing the feasibility of THz acceleration technology. A proof of principle THz acceleration experiment based on laser-generated single-cycle THz pulses with 10 μJ pulse energy at 0.45 THz has been performed recently [1]. First THz guns based on a parallel plate THz waveguide have been reported producing quasi-monochromatic 400 eV electron bunches with a few percent energy spread [2]. More advanced THz gun structures driven using either single-cycle or multi-cycle THz pulses have been proposed [3,4]. THz-based acceleration bridges the gap between micron-scale, ultra-compact IR-laser driven dielectric laser accelerators (DLAs) and meter-scale conventional accelerators. THz acceleration is similar to laser-plasma accelerators (LPAs) where a laser driven plasma bubble generates the strong THz fields for electron acceleration, however, in this work we generate the THz radiation by nonlinear optical means. These intermediate-scale devices combine many of the benefits of LPAs and DLAs, such as intrinsic synchronization and high acceleration gradients with the benefits of conventional accelerators such as high charge capacity, tunability as well as the robustness, stability and simple fabrication of static, macroscopic accelerating structures. In this work, a new THz waveguide structure that allows for electron acceleration and streaking driven by single-cycle THz pulses is described.

## THZ ACCELERATION

The schematic illustration of the experimental setup is shown in Fig.1 (a) with a photograph of the multilayer THz waveguide structure in Fig. 1 (b). A part of the fundamental (1030 nm, ~650 fs) laser beam is split into two output beams. One output is converted to 266 nm through fourth harmonic generation in BBO. The 266 nm UV pulses are directed onto a gold photocathode releasing ultrashort electron pulses. Photoelectrons are accelerated to 57 keV by a DC electric field between the photocathode and anode plates. Electrons interact with the THz field in the designed THz waveguide structure and are finally detected by a CCD camera with MCP. The single-cycle THz pulses are produced via optical rectification of the other IR output carrying 3 mJ pulses. This results in 10 μJ THz pulses with a center frequency of 300 GHz and polarization parallel to the electron propagation direction. Due to coupling loss and a long propagation distance, only around 5 μJ THz energy is coupled into the THz waveguide. The THz pulses need to overlap in space as well as in time with the electrons inside the cavity to produce an effective acceleration force. The optical time delay between the THz and electron pulses is adjusted by changing their path difference using a motorized delay stage. According to the Lorentz force law, particles of charge $q$ moving with velocity $\vec{v}$ in the presence of an electric field $\vec{E}$ and a magnetic field $\vec{B}$ will experience a force $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$. Since the polarization of the THz pulse is aligned with the electron's motion, with proper phase adjustment the electron beam can gain energy from the electric field of the THz pulse. In this experiment, the multilayer THz accelerator is designed in a way that matches the THz pulse front to the 0.44c velocity of the electron bunch. The phase front of the THz pulse is divided into several parts, which are isolated from each other by thin metallic surfaces (Fig. 1 (a)). For optimum acceleration, each individual acceleration length is matched to the dephasing length, which is the distance it takes the accelerated electrons to outrun the THz wave and slip into a decelerating phase. In each layer, dielectric materials are added to delay the arrival time of the pulse to the acceleration region. By properly designing the filling factor and thickness of each layer, cascaded acceleration of electrons throughout the whole phase front can be achieved [3]. The electron beam energy is measured via energy-dependent magnetic steering with a dipole located right after the accelerator. With the available THz pulse energy (5 μJ), a peak energy gain of 13 keV is observed by optimizing the electron beam voltage and arrival time of the THz pulse (Fig. 1 (d)). Figure 1 (c) shows the images of the electron beam with and without THz acceleration on the detector. We can see that both the final beam size and energy spread are larger than the initial injected electron beam, which is mainly due to the long initial electron pulse duration.

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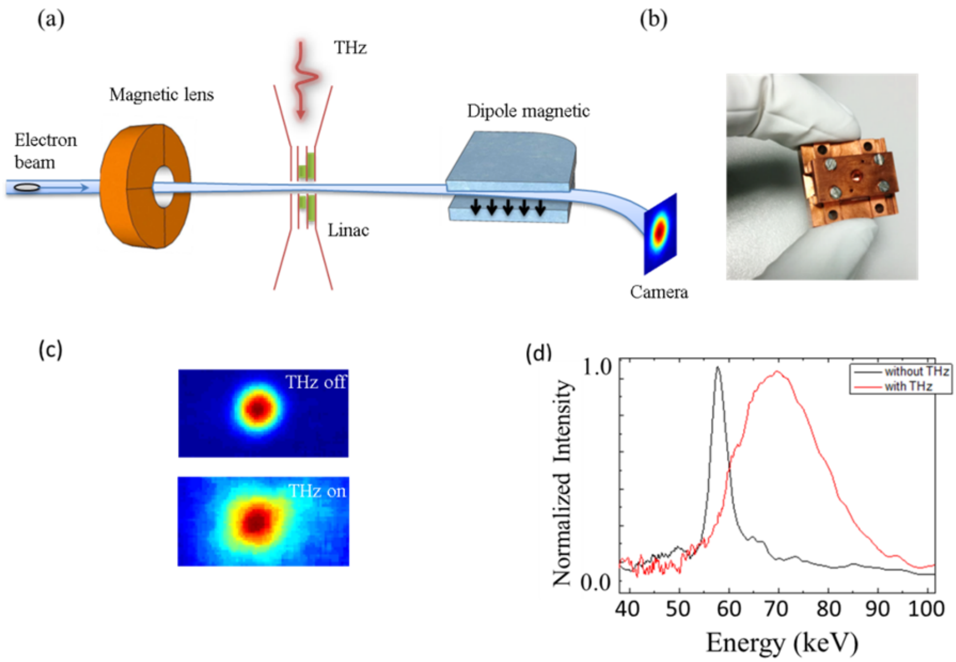


Figure 1: (a) Acceleration of an electron bunch from a 57 keV DC-gun using a multiple layer THz acceleration device with dipole magnet for energy measurement on MCP; (b) THz acceleration device; (c) Electron beam with and without THz acceleration on the detector; (d) Electron energy spectrum without (black) and with THz pulse (red).

## THZ DEFLECTION

Since the magnetic field of the THz pulse is perpendicular to the electron propagation path, according to the Lorentz force law the electron beam can acquire a temporally-varying transverse momentum which allows interpretation of the bunch temporal distribution. The amount of deflection and the streaking gradient are varied by adjusting the optical time delay between the THz and electron pulses using a motorized delay stage. For maximum streaking, the electrons should overlap with the linear part of the THz field. Figure 2 (a) shows the measured time dependent deflection which shows excellent agreement with numerical simulations (Fig. 2 (b)). The resultant maximum streaking speed measured exceeds 15 µrad/fs, which enables fs temporal resolution. This result also paves the way for THz-based characterization of relativistic electron beams in the MeV range.

## CONCLUSION

In conclusion, we have demonstrated a novel segmented waveguide structure that can serve as miniaturized electron linac as well as electron streak camera excited by single-cycle THz pulses. This device will find numerous applications in free electron lasers and ultrafast electron diffractometers.

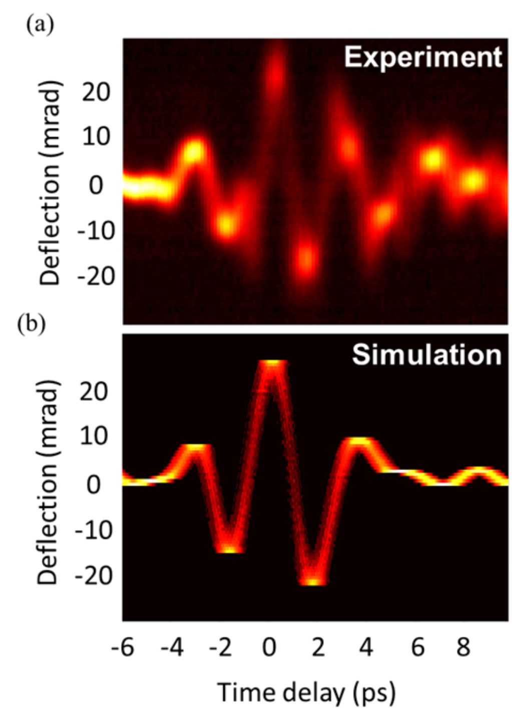


Figure 2: (a) Transverse deflection as a function of delay between THz-field and electron bunch; (b) Simulated deflection trace [5].




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