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THz-pulse-driven particle accelerators

Because of their suitable wavelength and temporal period, THz pulses with extremely high field strength are ideal for driving miniature particle accelerators. However, this fact is not yet well recognized. Here we give an overview of the possibilities and challenges of THz-pulse-driven electron and proton/ion accelerators.

Summary

According to numerical studies, with dielectric laser accelerators (DLAs) based on a double-grating dielectric structure it is possible to achieve loaded gradients exceeding 1 GeV/m [1]. Very recently, the working of such a miniature accelerator was demonstrated in proof-of-principle experiments [2]. However, these results also show the drawback of this approach: for a laser with about 1 μm wavelength the gap between the dielectric structures can be only a few hundred nm, thereby limiting the charge of the accelerated electron/ion bunch. In a recent publication we drew the attention to the fact that THz pulses with extremely high field strength available at present or becoming available in the near future, owing to their two orders of magnitude longer wavelength, are better suited for charged particle manipulation, including acceleration, bending, spatial or temporal focusing [3]. In this contribution we give an overview of the possibilities and challenges of THz-pulse-driven electron and proton/ion accelerators. Nowadays the main challenges are to achieve tens-of-mJ THz pulse energy and to optimize the geometry and the materials of the accelerating dielectric structure.

In the last ten years THz pulse generation with tilted-pulse-front-excitation [4] of $LiNbO_3$ (LN) resulted in the increase of THz energy by seven orders of magnitude, reaching the 100-μJ level [5]. In the next few years using optimal conditions (contact grating, long-pulse excitation, and cryogenic temperatures) will result in THz pulses with 10 MV/cm focused electric field strength and energies on the tens-of-mJ level [6].
According to numerical simulations using 20-mJ, 0.6-THz driving pulses for electron acceleration in dielectric-loaded metallic waveguides it is possible to accelerate a 1.6-pC electron bunch from 1 MeV to 10 MeV by simultaneously compressing it from 100 fs to 2 fs [7]. For such a device, and similarly for dielectric grating accelerators [1,2,8], using THz driving pulses rather than visible/near-infrared ones enables to exploit advantages of the two-to-three orders of magnitude longer wavelength and oscillation period of THz pulses. The allowed transversal size of the device is proportional to the wavelength. Larger transversal size allows larger bunch charge and results in larger throughput. Longer temporal period also allows a larger temporal jitter tolerance between the electron bunch and the driving pulse.

The dielectric grating accelerator can be used for acceleration of slow electrons and protons/ions, too, if the period of the structure is shorter than the wavelength of the driving pulse [9]. In this case evanescent fields are generated in the dielectric gap and this field accelerates the ions. We proposed another THz-driven device for postacceleration and monochromatization of proton beams [10]. Here two identical and synchronized THz pulses create the accelerating evanescent field between the two symmetrically arranged dielectric prisms. According to simulations, a proton bunch with 40 MeV initial energy can be boosted by 28% in this way.

In a joint project University of Pécs and HZDR work together to explore possibilities of THz-pulse-driven electron and proton acceleration. As a first step we plan to experimentally demonstrate the acceleration of slow electrons with intense THz pulses. Various dielectric structure geometries will be investigated to maximize the output energy. In the second phase intense THz pulses will be used to post-accelerate protons. First results of preliminary calculations on electron acceleration will be shown.

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