A Dielectric THz-driven Acceleration Setup Using a Metallic Waveguide: Simulations and Experiment.

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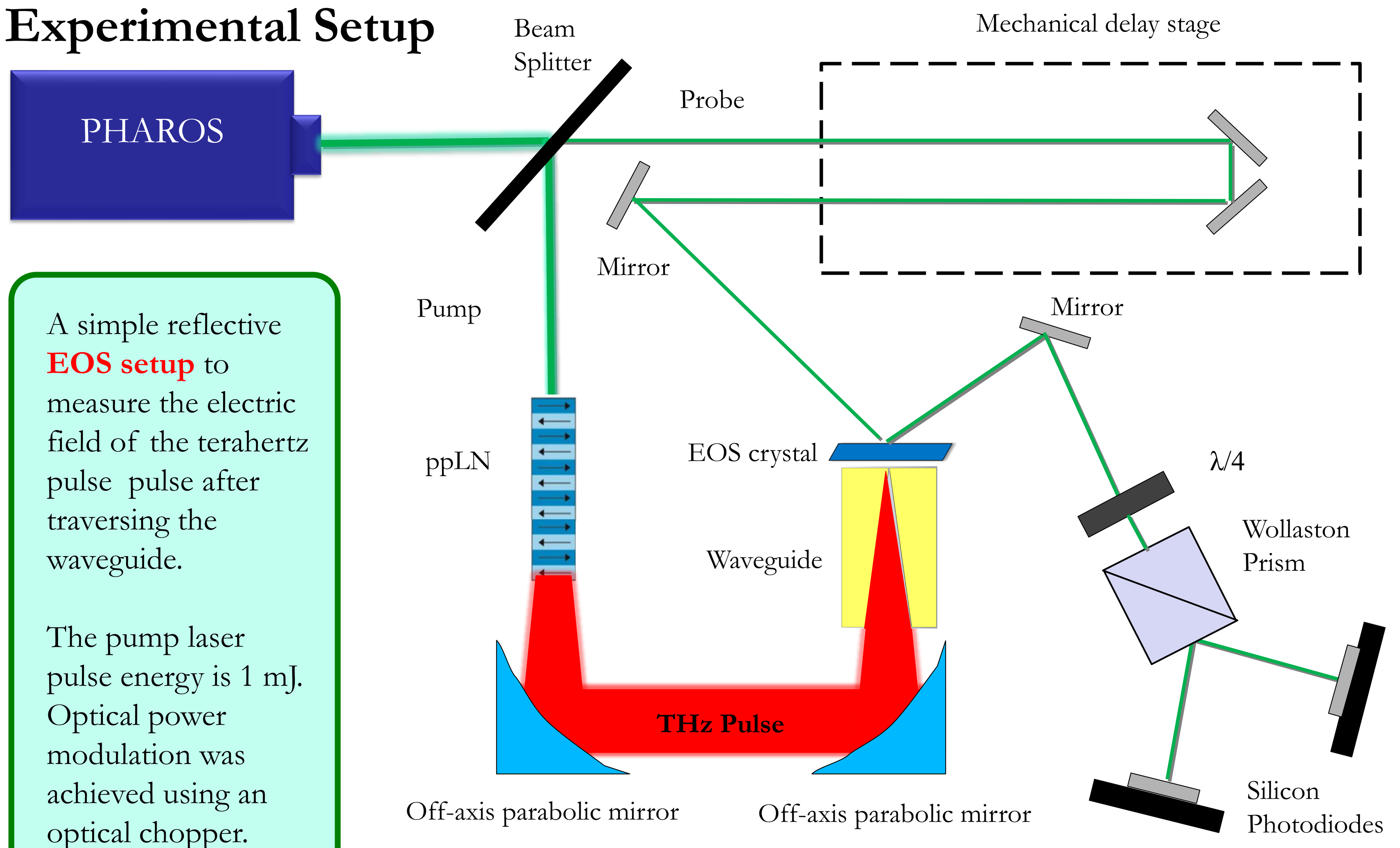
Introduction

- Nowadays high-energy particle accelerators **suffers two major problems**: The injected power must be limited to avoid cavity breakdown and their enormous size (and consequently, their cost).
- Dielectric Laser-driven Accelerators (DLAs) work under a different, novel acceleration concept to propel particles to high energies [1]. Dielectric materials possess a higher damage threshold than metals [2]. This feature allows for more intense electric fields inside the structure, enhancing the accelerator's performance. In 2013, it has been the first demonstration of a high accelerating gradient using a grating DLA [3], surpassing the values commonly found in RF cavities.
- Generally, the accelerating structure is fed using optical lasers. Thanks to their short wavelength, the accelerator dimensions can be reduced by several order of magnitudes. On the other hand, operating at these frequencies pose several challenges quite difficult to solve in practice [4].
- Thanks to the advance of the terahertz (THz) science in the last decades, they offers several advantages compared with infrared (IR) lasers, while keeping the benefits of structure-based laser-driven accelerators.
- A high percentage of laser-structure coupling is needed to attain high-gradient accelerators. **Our work combines a simple optical system to focus the generated THz pulse and a homemade metallic waveguide to generate a THz electric field suitable for particle acceleration.**

Experimental Setup



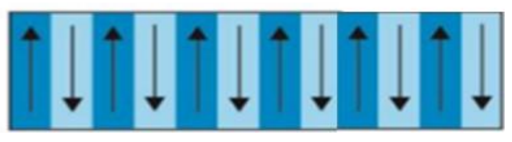
A simple reflective **EOS setup** to measure the electric field of the terahertz pulse pulse after traversing the waveguide.

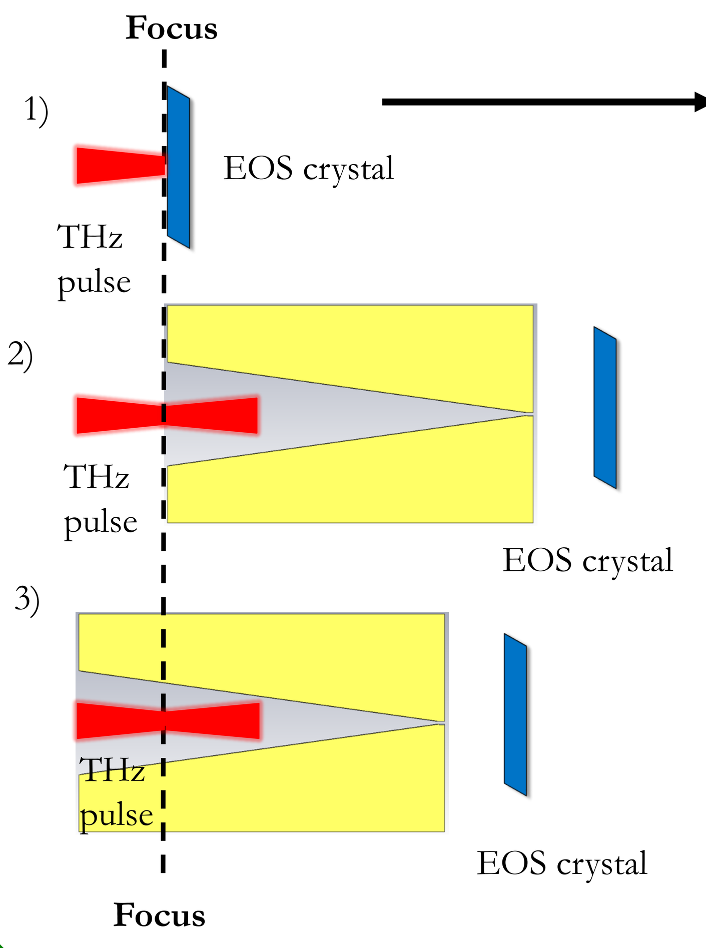
The pump laser pulse energy is 1 mJ. Optical power modulation was achieved using an optical chopper.

Multi-cycle THz Pulse Generation and Focusing

A six-cycle terahertz pulse is generated using a 6 pairs of ppLN waffers by quasi-phase-matched (QPM). The crystal consists of 12 wafers stacked alternating the direction of their optical axis. The central frequency is around 0.65 THz.

Periodically-poled Lithium Niobate (ppLN)





The THz pulse was measured for **three different configurations**. The first corresponds to a standard EOS, where the pulse is focused onto the EOS crystal. After this, we focused the THz pulse at the entrance of the waveguide and at 1-inch behind the entrance. In these two cases the EOS crystal was placed 3 mm after the waveguide to measure the electric field of the outgoing pulse.

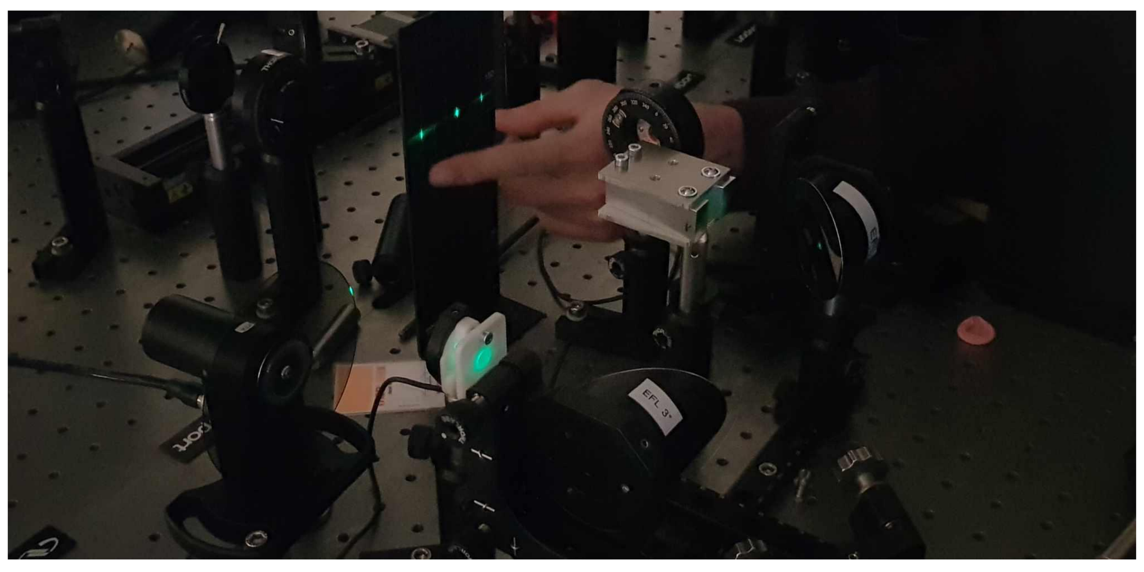
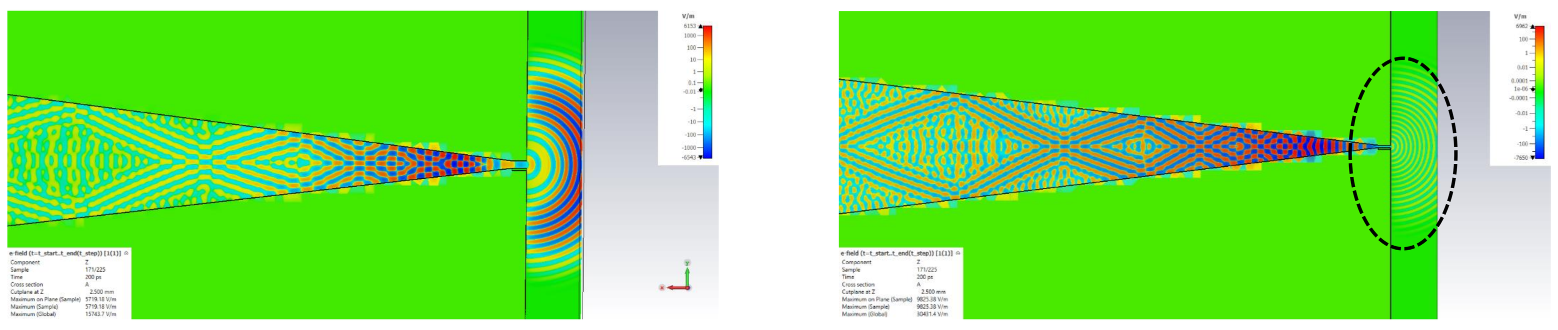


Photo of waveguide alignment by using visible light. A clear diffraction pattern can be observed on the laser's blocker

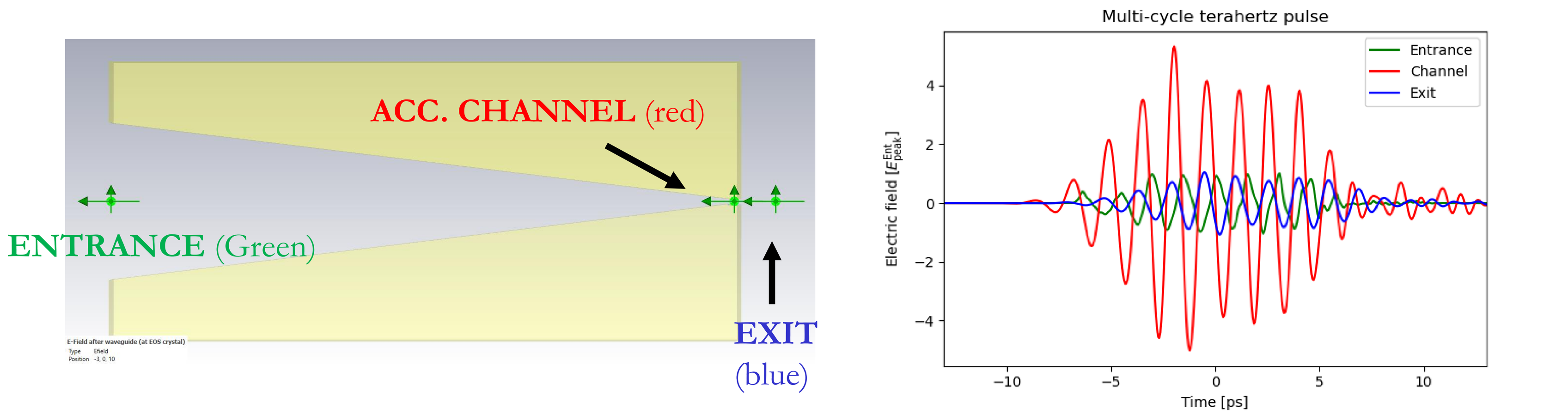
Results



Electric field map for a waveguide with gap equals to 400 μm (left), and 150 μm (right).

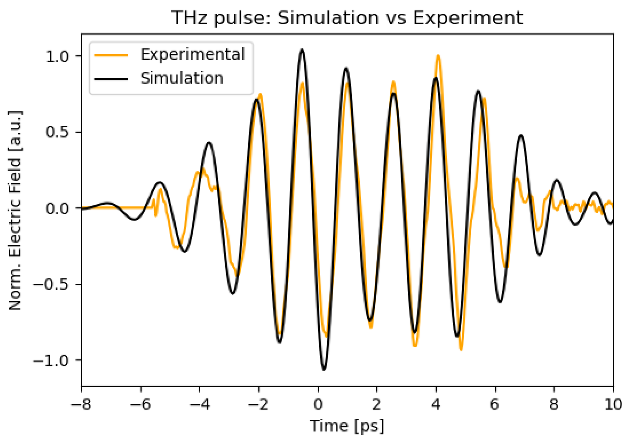
The **waveguide's geometry dictates** the propagation and transmission of the terahertz pulse. The THz pulse will be transmitted or not according to the waveguide's gap value (distance between the upper and lower parts of the waveguide, parameter *"a"* in equation).

$$\nu_{cutoff} = \frac{c}{2a}$$

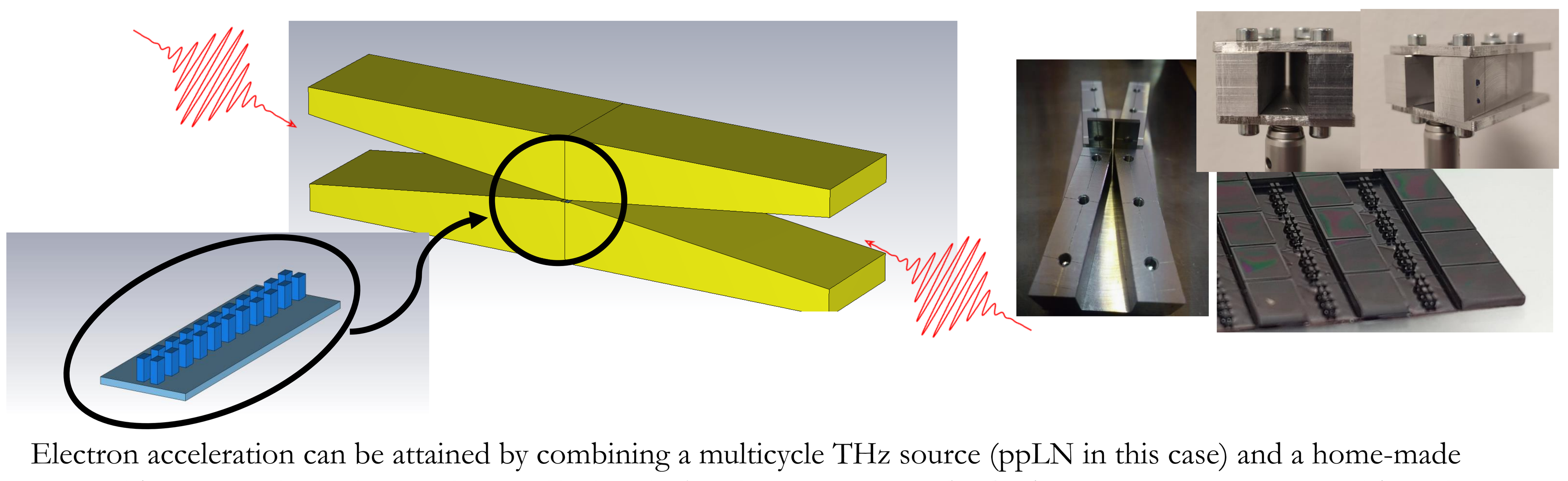


Left: Probes position inside the waveguide to study the pulse evolution inside the waveguide. Right: Electric field at the probes positions. The values are normalized to the entrance's peak electric field.

The waveguide was excited using the **measured THz pulse** with our experimental setup. As a result of the interaction with the waveguide, the THz peak electric field is amplified. The measured and simulated electric field for focus at entrance are in good agreement, **validating the simulation results** of the electric fields.



Experimental and simulation pulse for the entrance focus configuration. The shape resemblance between the pulses can be noted.

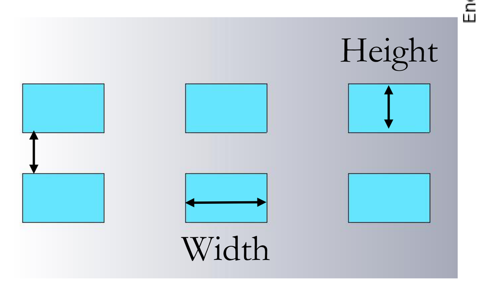


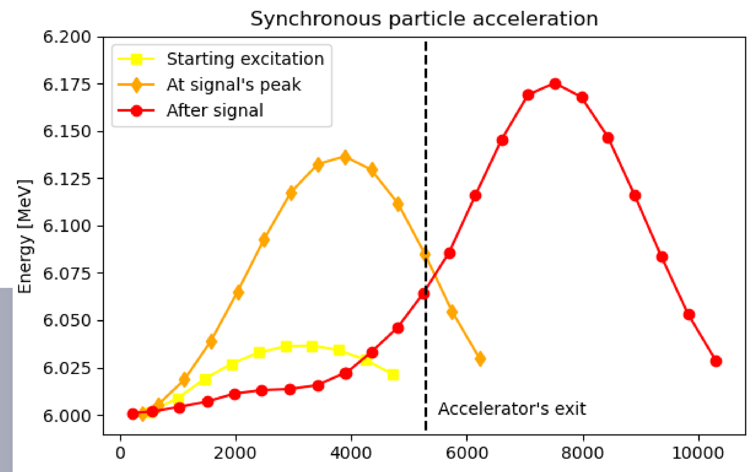
Electron acceleration can be attained by combining a multicycle THz source (ppLN in this case) and a home-made waveguide, to couple the laser pulse to a Dielectric Accelerator structure by feeding the symmetric waveguide with two pulses laterally.

The optimization of the DLA parameters such as the channel gap, the pillar height and width were carried out minding the figure of merits **acceleration factor (AF)**. The accelerating gradient is calculated in one period (λ_p), for the optimal electron path z(t). Exciting the waveguide with a THz pulse with peak field near 3 MV/cm results in an **energy gain of 0.175 MeV** in approximately 5 mm length for a initial bunch energy of 6 MeV.

$$AF = \frac{G_0}{E_{max}},$$

$$G_0 = \frac{q}{\lambda_p}\int_0^{\lambda_p} E_z(z(t), t)\, dz$$





Left: Structure parameters optimized for acceleration. Right: Energy profile at different time instants with respect to the THz pulse excitation.

Conclusion

- An electric field suited for particle acceleration was generated using a multi-cycle terahertz pulse with a metallic waveguide.
- Simulations reproduce very well the experimental results. Simulations can provide insight of the accelerating structure when the experimental techniques are unviable, and they can be used for
- The devised structure performance could be further improved by employing higher pump intensities, waveguide and DLA optimizations.

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