47th conference on Plasma Physics
Satellite Meeting
High-field laser-plasma interaction (HIFI)
Laser Driven particle and radiation sources for aplication (LASA)

Concept for a novel THz-driven narrow energy spread relativistic electron source

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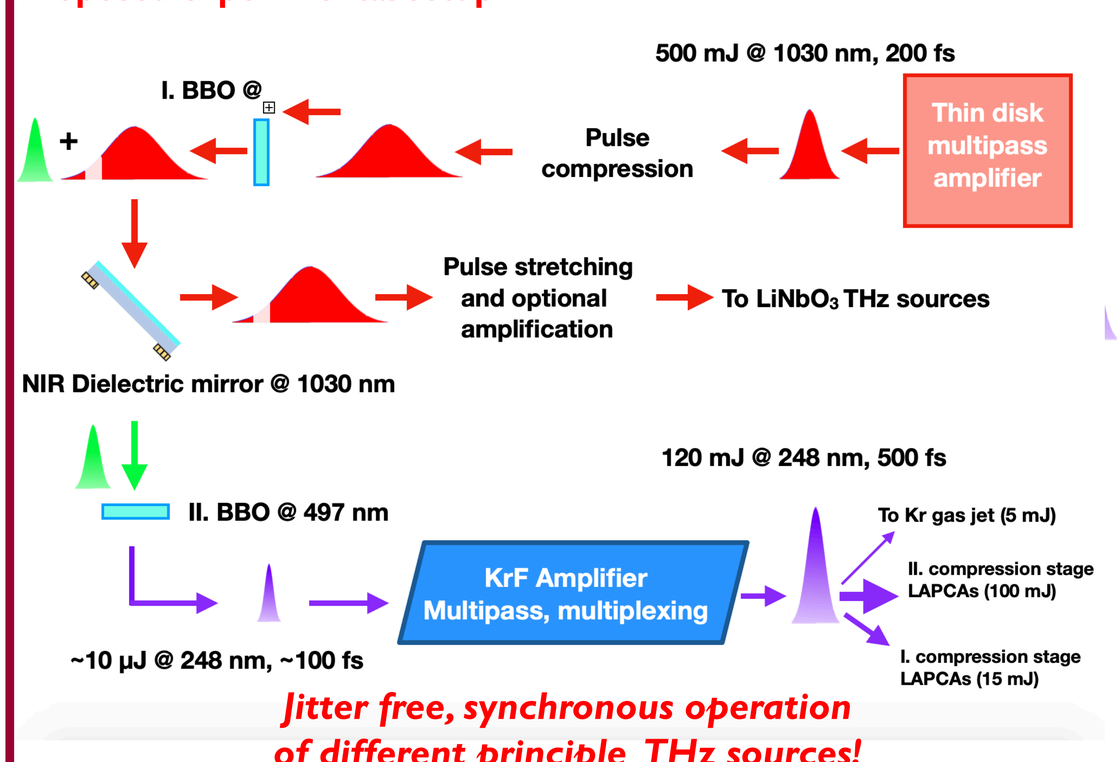
ABSTRACT

Numerical simulation of a novel hybrid THz-source based electron accelerator scheme is presented here. Numerous applications demand high energy, high brightness and short electron bunches, furthermore many of them require a narrow energy spread. Recent theoretical studies have demonstrated the possibility of such application-oriented electron sources, which are based on THz-driven electron gun and bunch compression stages [1]. In our proposed setup we combine the unique advantages of Optical Rectification (OR) in lithium-niobate and Large Aperture Photoconductive Antennas (LAPCA). OR based THz radiation provides GV/m accelerating fields while the low-frequency LAPCA source used for the compression, thus different parts of the THz spectrum can be utilized. For the latter purpose, recent advances in the research of LAPCAs provide a new opportunity. Nowadays, high electric field strength and >10 μJ pulse energies can be routinely achieved by wide band-gap semiconductor antennas at extremely low (0.05 THz) frequencies [2]. For preliminary calculations, single cycle LAPCA sourced THz pulses are compared for electron bunch-shaping. Assessment on the feasibility of a short pulse KrF amplifier chain as an optical driver for both electron and THz pulse generation is also considered.

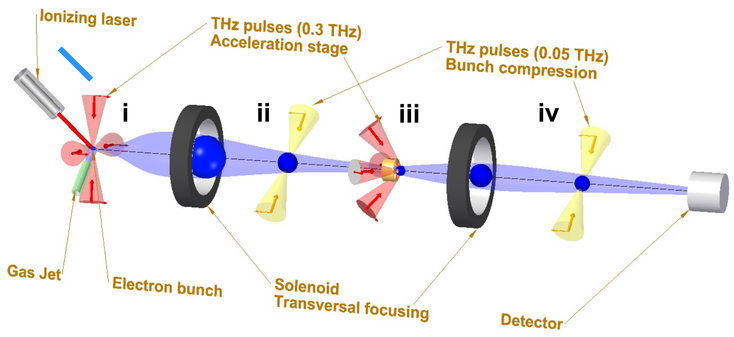
Motivation

Demand is growing from the scientific community for compact, cost-effective methods to generate high energy, narrow energy spread electron sources. Practical applications include: extremely high resolution electron microscopy, Auger-electron measurements, secondary x-ray sources and spectroscopy etc. Terahertz based solutions provide exceptional accelerating gradients on the order of GV/m [3]. While investigation of applying such fields for particle bunch shaping is still a new area of research, recent studies confirm this possibility [1]. For this purpose, practical acces to the lower frequency part of THz spectrum is highly desirable, due to the longer interaction lengths. Our main goal was to theoretically demonstrate that sub-THz pulses from photoconductive antennas can be synchronously applied in compact accelerator designs.

Proposed experimental setup



Jitter free, synchronous operation of different principle THz sources!

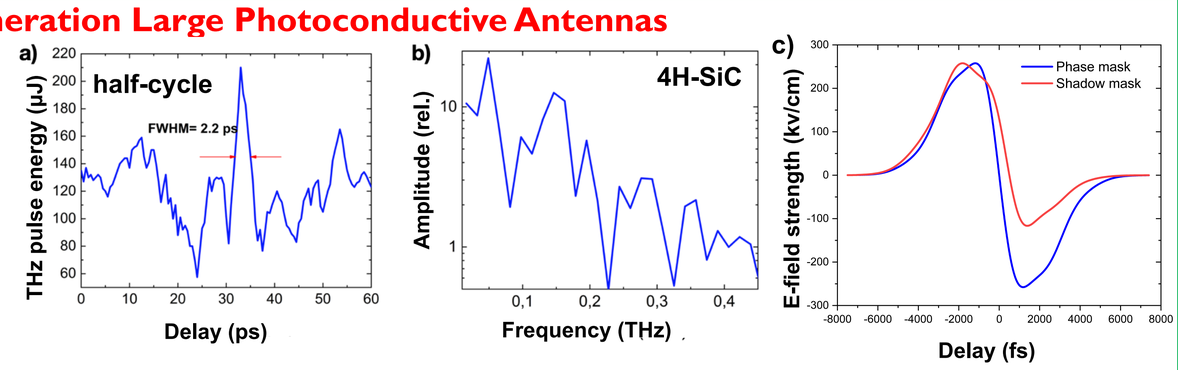


It should be noted that in order to provide seed pulses to the KrF amplifier, the third 3ω harmonic of a Ti:Sapphire laser can also be used.

Efficient generation of electron bunches via multi-photon ionization of gas jet (and other) targets is also another added benefit of the KrF ampifier, requiring only mJ energy scale, thightly focused UV pulses.

Next generation Large Photoconductive Antennas

Fig. 1.



It has been shown recently [2], that LAPCAs fabricated with wide band-gap semiconductors (4H-SiC) can be pumped using short-pulse, high photon energy (5 eV) KrF laser pulses. Results of the spectral characterization (Fig. a,b) showed a central frequency of 0.05 THz, allowing for the application of the extremely low end of the THz spectrum. Figure c) shows the waveform of the reconstructed electric field for both single and quasi-half-cycle THz pulses.

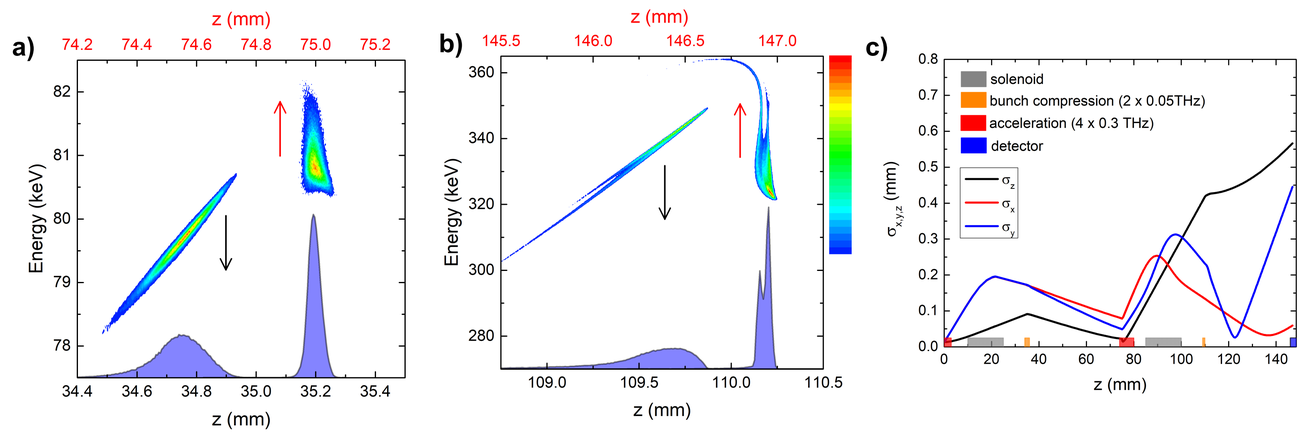
With improved antenna designs, and continuous developements in semiconductor fabrication technologies, pulse energies up to 100 μJ is expected in the near future.

Numerical simulations

The calculations were carried out with a particle tracer and a home developed software package. The computational method accounts for the three dimensional space-charge and relativistic effects as well. The parameters used during the simulations are identical to [2], except for the compression stages, where only two (instead of four) counterpropagating single cycle 0.05 THz frequency pulses are presumed. The simulational conditions are the following:

Parameter	Acceleration (i and iii)	Compression (ii)	Compression (iv)
Mean frequency	0.3 THz	0.05 THz	0.05 THz
Pulse duration	1.66 ps	4.4 ps	4.4 ps
Beam waist	1 mm (λ_{THz})	5 mm (λ_{THz})	5 mm (λ_{THz})
Pulse energy	0.5 mJ	3 μJ	100 μJ
Peak electric field	3.68 MV/cm	44.2 kVcm	258 kV/cm

Preliminary results



Results of the numerical simulations. Fig. a) describes the electron bunch spread (phase-space: upper red scale, energy spread: lower black scale) just before the second accelerating, and after the first compression stage at different positions along the propagation axis. Fig. b) shows a similar calculation at the second compression stage, and at the detector position. Fig. c) describes the spatial spread of the particle bunch in three dimensions and along the whole propagation axis. The resulting energy spread is less than <1%. From these results it's clear that low frequency THz pulses generated by LAPCAs provide a more effective, and simpler method for particle bunch compression.

Conclusions

- ***Synchronous application of OR and LAPCA THz generating techniques are possible for compact electron accelerator schemes (and other applications).***
- ***KrF amplifiers offer a feasable method for particle generation via short laser pulse interaction.***

The project has been supported by the European Union, co-financed by the European Social Fund. **EFOP-3.6.2-16-2017-00005**- *Ultrafast physical processes in atoms, molecules, nanostructures and biological systems.*

References

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