ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPRB067

HIGH-GRADIENT SINGLE CYCLE TERAHERTZ ACCELERATING STRUCTURES*

Sergey Kuzikov†, Sergey Antipov, Edgar Gomez, Euclid Techlabs LLC, Bolingbrook, IL, USA
Alexander Vikharev, Institute of Applied Physics of Russian Academy of Sciences, Nizhny Novgorod, Russia

Abstract

Recently, gradients on the order of 1 GV/m level have been obtained in a form of single cycle (~1 ps) THz pulses produced by conversion of a high peak power laser radiation in nonlinear crystals (~1 mJ, 1 ps, up to 3% conversion efficiency). These pulses however are broadband (0.1-5 THz) and therefore a new accelerating structure type is required. For electron beam acceleration with such pulses we propose arrays of parabolic focusing micro-mirrors with common central. These novel structures could be produced by a femtosecond laser ablation system developed at Euclid Techlabs. This technology had already been tested for production of several millimetres long, multi-cell structure.

SINGLE CYCLE THZ GATED RF GUN

A permanent problem for any RF gun photoinjector is to obtain high brightness, low-emittance, low energy spread beam. One of appealing solution is to use a so-called THz ultrafast field emission gating. High peak cathode field is necessary to achieve a high brightness (low emittance) beam to be accelerated to relativistic energies before space-charge effects spoil the bunch. High-field single cycle THz pulses are now produced by means of laser light rectification in a nonlinear crystal [1]. Such pulses can provide ~1 GV/m pre-acceleration of sub picosecond bunches in RF gun's resonator (Fig. 1).

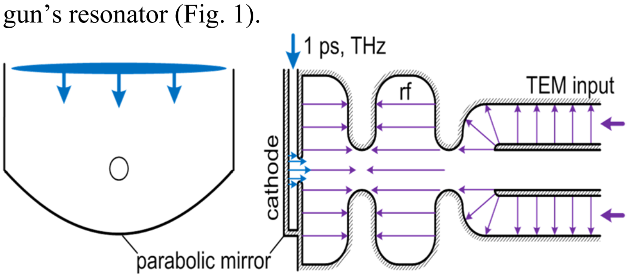

Figure 1: RF gun wherein electron emission is controlled by a picosecond THz pulse irradiating a metallic cathode.

The 1 GV/m field strength of the THz pulse, combined with the RF gun accelerating field of ~100 MV/m, results in the emission of a short current pulse from the cathode. Compared to a standard photocathode, the beam brightness is increased due to the high additional accelerating field provided by the THz pulse. The proposed injection scheme does not require a UV laser, high emission charge (up to 1 nC) is produced due to field emission at high THz fields for sub-picosecond bunch lengths.

* This work was supported by the Russian Science Foundation under Grant 19-42-04133 in the part of CST simulations for THz structures.
† s.kuzikov@euclidtechlabs.com

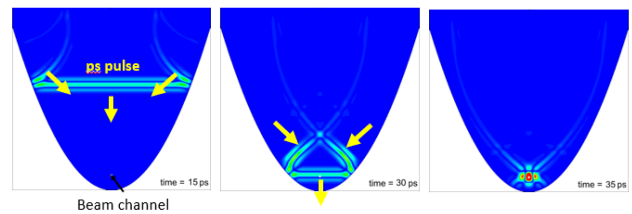

Figure 2: E-field distributions at the parabolic mirror while focusing the short THz pulse, for the time correspondent to beginning of focusing at t=15 ps (left), for time when focusing is close to maximum at t=30 ps (center), and in maximum of focusing (right) at t=35 ps.

Table 1: Anticipated Parameters of the Targeted THz-gated Injector.

Parameters	Value
Cathode field, GV/m	8
Bunch length, ps	0.13
Cathode radius, mm	8×10^{-3}
Bunch charge, pC	25
ε_{th}, mm×mrad	9×10^{-4}
ε_{sc}, mm×mrad	0.13
ε_{RF}, mm×mrad	7×10^{-3}
B	2.2×10^{16}

In order to obtain the highest emission fields the THz pulse is focused to the smallest possible size at the cathode by means of a parabolic mirror (Fig. 2). Such scheme is well suitable for the use in a conventional RF gun. The parabolic mirror allows efficient focusing of the broadband THz pulse. The anticipated parameters of the THz injector are summarized in the Table 1.

BROAD BAND THZ ACCELERATING STRUCTURES

In [2-6] a new accelerating structure design was proposed which introduces a set of waveguides with different adjusted lengths. In this concept acceleration of a charged particle occurs inside of the parabolic mirror that focuses the broadband, short THz pulse. To provide a long range acceleration a stack of such paraboloids is employed with timing delay between them for synchronization with charged particle. Such delay can be produced by geometrical path difference for THz pulse or dielectric delay line.

Concept of Delay Waveguides

According to this concept, accelerating structure design requires empty waveguides with different adjusted lengths, in which the synchronism of accelerated particles with

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPRB067

transversely propagating picosecond THz pulse will be maintained (Fig. 3).

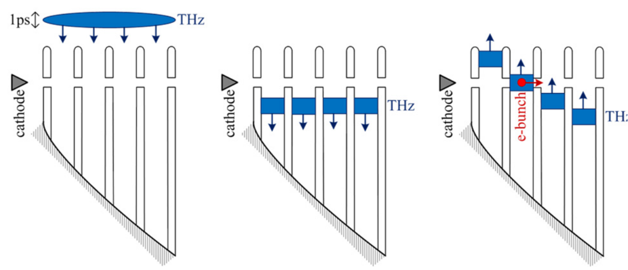

Figure 3: Sketch of particle acceleration in a structure by picosecond THz pulse for three sequent time frames.

Dielectric Delay Concept

This concept exploits dielectric slabs of different lengths inserted in the THz pulse propagation path (Fig. 4). In the transverse direction of Fig. 4 the accelerating structure consists of focusing parabolic mirrors similar to the one introduced in Fig.. 2. These mirrors enhance the accelerating field seen by electrons. Such design allows to reduce overall Ohmic losses and to mitigate negative action of frequency dispersion in the waveguide. The structure in Fig. 4 is fed by single-cycle THz pulse propagating in parallel to metallic blades (E-field is perpendicular to these blades). Delay lines provide necessary synchronism of a short electron bunch flying through the structure. Field and bunch dynamics are shown in Fig. 6.

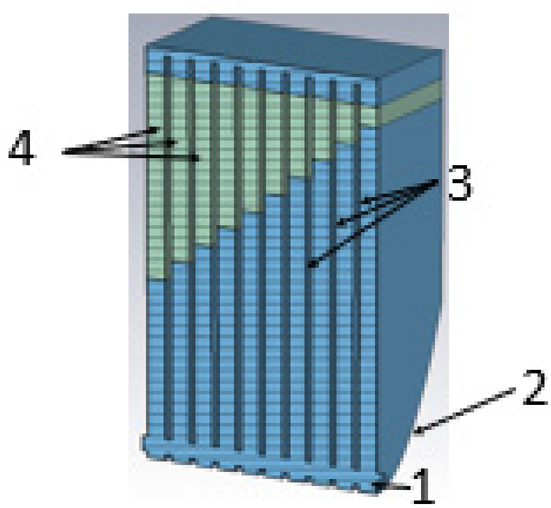

Figure 4: Sketch of broad band THz structure based on dielectric delay waveguides: 1 – beam channel, 2 – mirrors of the parabolic shape, 3 – oversized vacuum waveguides, 4 – delay waveguides filled with dielectrics.

Parameters of the proposed structure are presented in the Table 2. Assuming 1 mJ, 1 ps THz pulse the relativistic electron will gain 0.4 MeV energy with an average gradient is of 0.3 GV/m.

Table 2: Parameters of THz Accelerating Structure Fed by 1 ps THz Pulses:

Parameters	Value
Number of cells	10
Dielectric permitivity	3.75
Cell length	0.26 mm
Focal length	0.18 mm
Iris thickness	0.06 mm
Width	2.5 mm
Length	2.6 mm

Production Technology

The described broad band THz structure could be produced by femtosecond laser ablation. The prototype structure of 2.5 mm length was produced using fs laser ablation technology (Fig. 5). This structure was assembled of 10 copper plates. In each plate we ablated the parabolic mirror and the 200 micron diameter hole for electrons. These plates were stacked together so that holes introduced the common channel for e-beam. In Fig. 5 one can see ∅0.2 mm wire inserted into the beam channel.

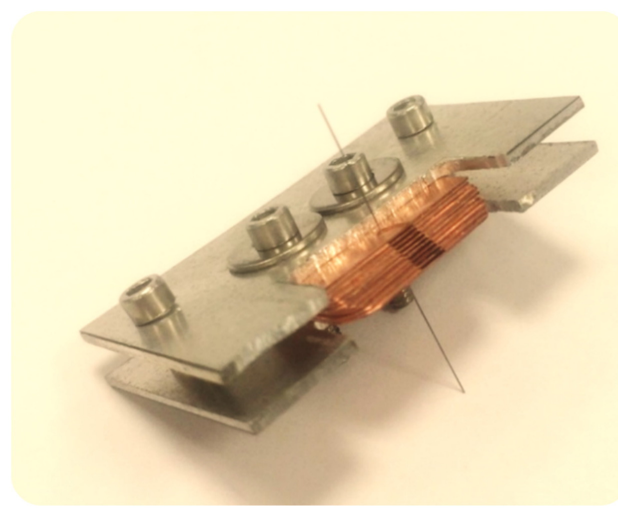

Figure 5: First prototype produced from stack of copper parabolic waveguides.

CONCLUSION

Using ultrafast terahertz gating for the preliminary acceleration of bunches allows to gain beam brightness. The highest acceleration gradients (~GV/m level) could be reached using picosecond single-cycle THz pulses produced by conversion of laser radiation in nonlinear organic crystals. We propose new broadband THz structures which can utilize such short pulse for extended length acceleration of electrons.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPRB067

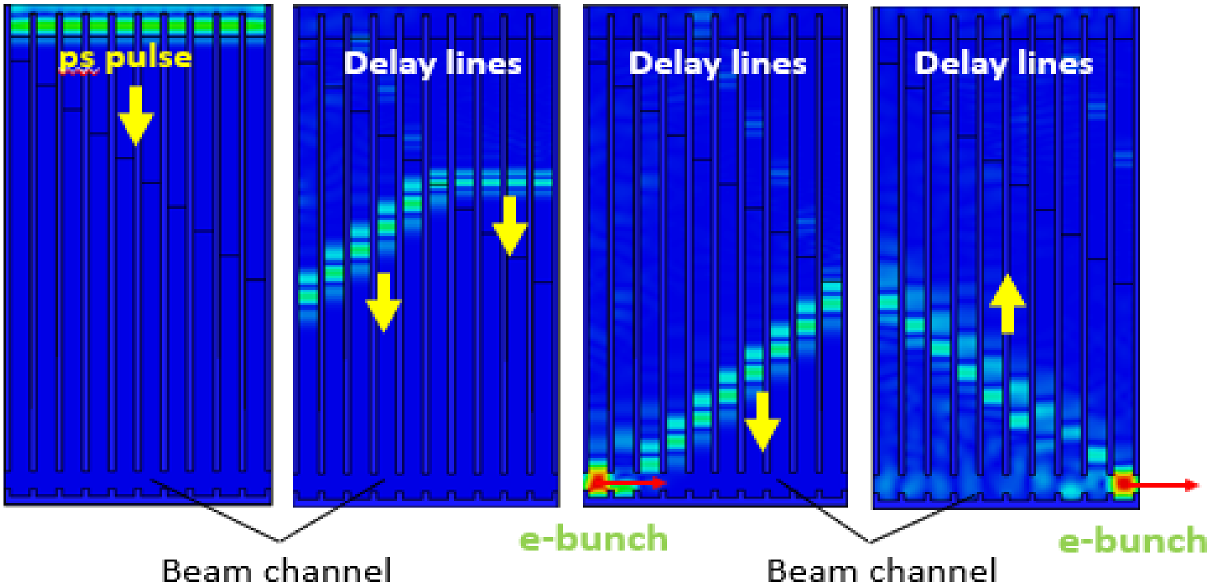

Figure 6: Front view of dielectric delay line THz accelerating structure (time proceeds from left to right).

REFERENCES

[1] C. Vicario, A. V. Ovchinnikov, S. I. Ashitkov, M. B. Agranat, V. E. Fortov, and C. P. Hauri, "Generation of mJ pulses in the 0.1-5 THz gap with electric field exceeding 80 MV/cm," *Opt. Lett.*, vol. 39, No. 23, pp. 6632–6635, 2014.

[2] S. V. Kuzikov, A. E. Fedotov, N. Yu. Peskov, A. N. Stepanov, A. A. Vikharev, "Millimeter and submillimeter-wave, high-gradient accelerating structures", *AIP Conf. Proc.*, vol. 1812, p. 060002, 2017.

[3] S. V. Kuzikov, S. Shchelkunov, A. A. Vikharev, "Concepts for a Short Wavelength rf Gun", *AIP Conf. Proc.*, vol. 1812, p. 080005, 2017.

[4] Yu. A. Sergeev *et al*,"Strong terahertz fields: interaction with condensed matter and electron acceleration" *EPJ Web Conf.*, vol. 149, p. 05009, 2017.

[5] S.V. Kuzikov, O.A. Ivanov, A.A. Vikharev, A.L. Vikharev, S. Antipov, "NOVEL CONCEPTS OF A HIGH-BRIGHTNESS PHOTOINJECTOR RF GUN ", Proc. of 38th FEL Conf., Santa Fe, pp. 389-392., 2017.

[6] S.V. Kuzikov *et al*, "Quasi-Optical THz Accelerating Structures", *AAC2018 Workshop*, 12-17 August 2018, Breckenridge, Colorado.