Multi-Cell Accelerating Structure Driven by a Lens-Focused Picosecond THz Pulse

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Recently, gradients on the order of 1 GV/m level have been obtained in a form of a 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) [1]. Such high intensity radiation can be utilized for charged particle acceleration. However, these pulses are short in time (~1 ps) and broadband, therefore a new accelerating structure type is required. In this paper we propose a novel structure based on focusing of THz radiation in accelerating cell and stacking such cells to achieve a long-range interaction required for an efficient acceleration process. We present an example in which a 100 microJoule THz pulse produces a 600 keV energy gain in 5 mm long 10 cell accelerating structure for an ultra-relativistic electron. This design can be readily extended to non-relativistic particles. Such structure had been laser microfabricated and appropriate dimensions were achieved.
Laser – driven THz pulse production

Generation of 0.9-mJ THz pulses in DSTMS pumped by a Cr:Mg$_2$SiO$_4$ laser

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focusing optics and wavefront optimization [28]. Under these conditions, field strength of 80 MV/cm and 27 Tesla, respectively, is feasible, which surpasses any laser-based and accelerator based THz sources by about an order of magnitude in the frequency range of 0.1–5 THz.
Focusing by parabolic mirror, time-lapse
Timing THz pulses and e-beam

Each channel has to have delay to match electron speed

Timing by optical path delay: difficult to fabricate
Synchronization by dielectric delay
Experimental Realization

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Short electron bunch generation using single-cycle ultrafast electron guns

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Segmented terahertz electron accelerator and manipulator (STEAM)

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Delay line + lens for field concentration

Focusing by silicon lens

Multi-cell structure
Total input: 116 uJ of THz energy
With total of 10 uJ per cell delivered, maximum accelerating field reaches 385 MV/m.

Table 1: Parameters of THz accelerating structures:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Silicon</th>
<th>Quartz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cells</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Dielectric permittivity</td>
<td>11.9</td>
<td>3.75</td>
</tr>
<tr>
<td>Cell length</td>
<td>0.2 mm</td>
<td>0.2 mm</td>
</tr>
<tr>
<td>Beam pipe diameter</td>
<td>0.1 mm</td>
<td>0.1 mm</td>
</tr>
<tr>
<td>Focal length</td>
<td>0.2 mm</td>
<td>0.2 mm</td>
</tr>
<tr>
<td>Iris thickness</td>
<td>0.2 mm</td>
<td>0.2 mm</td>
</tr>
<tr>
<td>Width</td>
<td>3 mm</td>
<td>3 mm</td>
</tr>
<tr>
<td>Length</td>
<td>4 mm</td>
<td>4 mm</td>
</tr>
</tbody>
</table>

Energy gain along the length of the structure
Delay line + lens – monolithic unit!

These units will be stacked on top of each other to form a multi-cell structure...

High Resistivity Silicon cut by femtosecond laser
Metrology: confocal laser scanning microscope (Keyence)