High Power Tests of Millimeter Wave Accelerators

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The 13th Workshop on Breakdown Science and High Gradient Accelerator Technology
Terahertz-Driven Acceleration, Sources and Pulse Generation

Need advanced techniques for high peak power narrowband THz sources
=> Efficient accelerators

Normal conducting rf accelerator structures (TM single cells)

\[ \sim f^{1/2} \]

\[ \sim f^{-2} \]

\[ \sim f^2 \]

Semiconductors
QCL
cryogenics

Microwave tubes
FEL

Science 318 (2007)
THz Metallic Structures Holds the Potential for High-Gradient Accelerators: Beam-Driven Mm-Wave Structures

- Beam driven (Collinear) acceleration

Accelerating gradient ~ 50 MV/m
Surface fields ~ 500 MV/m
Pulse length ~ 100 ps
Drive bunch 4 GeV, nC


Accelerating gradient ~ 85 MV/m
Pulse length ~ 2 ps
Drive bunch 30 MeV, pC


Characterization of externally-driven high gradient THz structures needed for achieving optimal operation
110 GHz single cell accelerator cavity

<table>
<thead>
<tr>
<th>Iris thickness [mm]</th>
<th>0.2</th>
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<tr>
<td>Quality factor $Q_0$</td>
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<td>Shunt impedance [MΩ/m]</td>
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<td>$E_{\text{surface}}/E_{\text{acc}}$</td>
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Future approaches include additive manufacturing
Prototyping and Assembly of Externally-Driven THz Accelerator Structures Using Split-Block Technology

110 GHz single cell accelerator cavity

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Future approaches include additive manufacturing

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Nanni et al., IPAC 2016.
Efficient Excitation of THz Accelerating Structures Using Quasi-Optical Coupling of rf Power

Free-space Gaussian beam coupled to structure
>90% efficiency

Efficient coupling into narrow-band accelerating structures to avoid lossy waveguides
Laser-Based Semiconductor Switch for Nanosecond rf Pulse Shaping

Irradiation of a Si wafer by the laser produced 110 GHz rf pulses with a 11 ns width

Othman et al., Appl. Phys Lett. 117.7 (2020)

Jawla, Mon. 10:15 AM
High Gradient Measurements at 110 GHz

Highest Gradient at 570 kW @ 11 ns

- Peak gradient 230 MV/m
- Peak surface field > 520 MV/m
- Peak pulse surface heating < 40 °C indicating no damage

Breakdown Properties

- Breakdown is detected through pulse shortening and detection of dark current emission
- No field emission detected in normal operation

Reliable measurements of high gradient and rf pulses is crucial
Rapid processing of the cavity is essential for high gradient applications.

High Brightness Field Emission THz Gun

- Two cell gun with 50 μm radius copper tip
- On-axis coupling from 110 GHz gyrotron source
- Maximum field on the tip is 3.8 GV/m for 500 kW input power

Field enhancement at tip

Acceleration

Tip

Coupling to circular waveguide

Axis of cylindrical symmetry

S. Lewis

1 mm
Field Emission Gun Cells Fabrication and Assembly: Additive Manufacturing Tools

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<tr>
<th>Dimension</th>
<th>Design</th>
<th>Measured</th>
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<tr>
<td>Inner iris radius</td>
<td>0.268 mm</td>
<td>0.281 mm</td>
</tr>
<tr>
<td>Coupler radius</td>
<td>0.408 mm</td>
<td>0.402 mm</td>
</tr>
<tr>
<td>Waveguide radius</td>
<td>1.185 mm</td>
<td>1.180 mm</td>
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Field Emission Gun Cells Fabrication and Assembly: Additive Manufacturing Tools

Coupling iris

Inner iris

3 mm

S. Lewis
Demonstrate feasibility of using normal conducting, THz accelerating structures to create compact ultra bright electron sources for EM applications
Novel Beam-Wave Interactions at THz Frequencies: Broadband THz Accelerator Structures [Picosecond pulses, ~ MW Peak Power]

- Laser driven THz acceleration

>100 MV/m

THz E field [a.u.]

~100 MV/mm

Time [ps]


Snively, Othman et al., PRL 124.5 (2020).


50 MV/m

2 MV/m

THz race heats up with new high gradient technologies


Ultrashort Bunch Generation for Ultrafast Electron Diffraction Using THz-Driven Compression and Time-Stamping

- Single cycle THz pulses
- High peak power for efficient
- Kick ~10 keV/100 fs


Pump laser ~25 fs rms
Electron bunch length ~100 fs rms
Timing jitter ~25 fs rms


Snively, Othman et al., PRL 124.5 (2020).
Narrowband High Gradient THz Accelerators: Leveraging laser-Driven THz Sources

Target:
- Pump laser system | > 100 mJ pulse energy
- High-energy sub-THz-wave generation | > 100 kW (>10 μJ, ~100 ps)

Preliminary result:
- 0.46-THz generation (unseeded BW-TPO & DFG) with 15-mJ pump laser system

Toward 100 MeV/m acceleration with laser-generated THz pulses
• Mm-Wave/THz accelerating structures promise high gradient toward achieving GeV/m with compact footprint
• Performance of THz structures under high gradient depends on rf design, assembly and excitation
• High gradient structures at 110 GHz tested demonstrate record high gradient >230 MV/m and fast processing < 10^5 pulses
• Field emission gun is in line for testing (2021)
• G-band structure and THz accelerators are showing practical use
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