# Laser-generated Terahertz Acceleration

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#### Dielectric & Structure THz acceleration

Mediating gap between RF and Dielectric Laser Acceleration



- wakefields
- Millimetre scale wakefields
- Broadband pulses controlling dispersion
  group velocity walk off



- Oscillation period femtosecond regime
- Oscillation period *too short*,
  accelerating bucket << injection capability
- Small apertures: wakefields; beam transport; manufacture



### THz generation by Optical Rectification

Difference frequency mixing by broadband ultra-short optical pulse







### THz acceleration, bunching & streaking

Growing interest, activity and demonstrations



#### THz acceleration & deflection @ Cockcroft Institute

#### THz driven injector

• 100keV DC photo-gun and THz-driven structures for acceleration & deflection

# THz driven acceleration & deflection of relativistic beams

• 50MeV electron beam of CLARA as testbed

#### THz source development

#### Single-cycle pulses

- highest field strengths,
- group & phase velocity matching limits

#### Narrow-band pulses

- Bandwidth and frequency tuneable sources being developed through chirped-pulse beating
- 5cycle 20-cycles

#### Polarisation states and transverse profile (mode coupling)

- · Require longitudinal field for acceleration
- Transverse polarisation profile matching for mode-selection



S Jamison Linac'18, Beijing, September 2018

#### THz driven structures

#### Velocity matching design

- · Matching phase velocity to electron
- group & phase velocity matching limitations; dispersion and group walkoff

#### THz travelling source concept

• Dispersion-free propagation of single-cycle pulses



#### Dielectric-lined waveguides for velocity matching



### Dielectric-lined waveguide Manufacture



- Rectangular-shaped Dielectric-Lined Waveguide (DLW).
- Hollow copper structure lined with fused silica, 200 μm wide aperture.
- Tapered horn used to couple THz radiation into the waveguide.
- Designed to either deflect or accelerate 100 keV electrons.

Dimension	Size (µm)
Waveguide width, w	1000
Dielectric slab separation, 2a	200
Dielectric slab thickness, t	242
Waveguide length, L	10000
Coupler length	44000





### Dielectric-lined waveguide Coupling







#### THz Electro-optic Time-Domain Network Analyser



#### THz electro-optic time-domain Network Analyser



#### Laser-driven THz sources for acceleration

Photoconductive antenna



#### Laser-driven THz sources for acceleration Non-linear Optical Materials

Paired non-linear polarisation/source for opposite polarity THz fields







# Laser-driven THz sources for acceleration

High-field Cherenkov Non-linear Optical Materials



1 MV/m longitudinal fields with modest <1mJ laser energy now have 200mJ laser available



#### THz Generation – spintronic emitters



Ferromagnetic layer: CoFeB Non-ferromagnetic: Pt Substrate: MgO

[5] T. Seifert, Nature Photonics, **10**, pages 483–488 (2016)



Reported <u>transverse</u> THz electric field of **300 kVcm<sup>-1</sup>** for large-area spintronic source

T. Seifert *et al., Appl. Phys. Lett.* **110**, 252402 (2017)

- Polarization dependence
  - Terahertz polarization is perpendicular to the applied magnetic field



- Magnetic-field patterning
  - The magnetic structure of the source can be manipulated to alter the emitted terahertz polarization





# Spintronic source



Transverse polarization





#### Spintronic source Longitudinal polarization Amplitude (arb. units) 500 1000 1500 2000 4 6 0 **Aligned magnetic polarity** (a) (b)





E<sub>THz</sub> (kVcm<sup>-1</sup>) -2 0 2

-6 -4

### Travelling-source THz-driven acceleration

Dispersion-free, sub-luminal, propagation of single-cycle pulses

High field strength THz because they are single-cycle. How to propagate without dispersion?

Intrinsically broadband - waveguide propagation can not maintain field strength Single-cycle - transverse pumping &  $\pi$ -phase jump structure not applicable





## Travelling-source THz-driven acceleration



### Travelling-source THz-driven acceleration



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### Travelling source THz-driven acceleration



Measuring the Travelling-source in the near-field



- Dispersion free propagation, at tuneable velocity
- Subluminal propagation with  $v_{\phi} = v_g < c$





### Travelling source THz-driven acceleration

#### High-field Cherenkov non-linear rectification sources

Normal Cherenkov source Pulse-front tilt to match Cherenkov angle







### THz deflection of 100keV electrons

Travelling source experiment



### THz acceleration of 30 MeV electrons

CLARA test accelerator, STFC Daresbury Laboratory

THz acceleration experiments in late stages of preparation beam-time October-November 2018



Phase-I electron beam: 40MeV, <200fs rms





#### In summary

- THz driven acceleration and deflection demonstrations coming on-line
  - Streaking and acceleration of sub-relativistic beams (<100keV) demonstrated
  - Streaking of relativistic beams demonstrated
  - Experiments for relativistic beam acceleration in preparation for CLARA
- THz sources developed
  - Longitudinal polarisation and transverse mode control
  - Broadband, singe-cycle sources & narrow-band sources available
- Structures and novel sources for THz-particle velocity matching





#### THz acceleration Group Cockcroft Institute

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...with some missing













