A DIELECTRIC-LINED WAVEGUIDE FOR TERAHERTZ-DRIVEN ELECTRON MANIPULATION AND ACCELERATION

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OUTLINE

- Introduction
- DLW mode description
- THz source and pulse propagation
- Coupler design
- Electron manipulation
- Experimental plans

WHY DIELECTRIC AND WHY TERAHERTZ?

Dielectric-lined waveguides

- Have potentially high accelerating gradients
- Allow the wave to propagate with phase velocity $v_p \leq c$

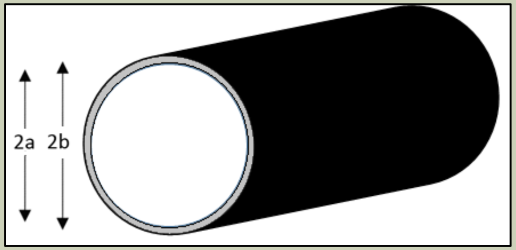
Terahertz wavelengths

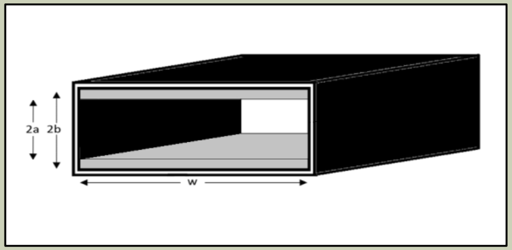
- Breakdown threshold scales as $f^{1/2}\tau^{-1/4}$ - moving from RF to THz increases the breakdown limit
- Preferable over optical wavelengths – structures are large enough to fabricate conventionally and can be simpler travelling wave designs

STRUCTURE DESIGN

Cylindrical waveguides:

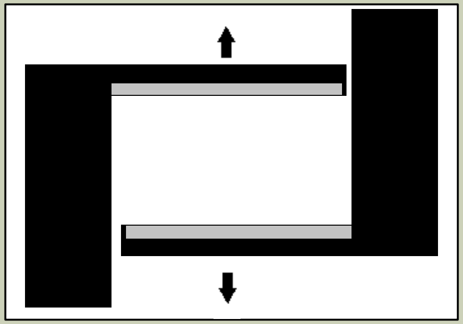
- Higher shunt impedance and accelerating gradients
- Tolerance requirements on fabrication potentially difficult to meet

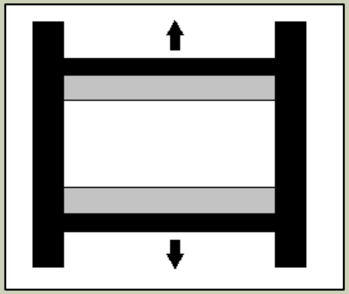




Rectangular waveguides:

- Simpler to fabricate
- Dielectrics such as CVD diamond can be made easily as planar layers
- Potential for tuneability





STRUCTURE DESIGN

Choice of dielectric

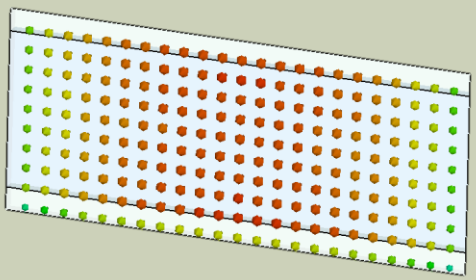
- Quartz
- **CVD diamond**
- Sapphire

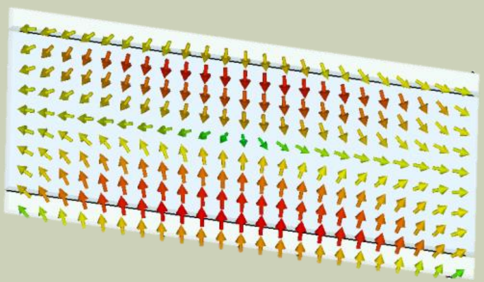
Why CVD diamond?

- Fabricated in-house
- Very high breakdown field
- Low loss tangent ($<10^{-4}$)
- Highest known thermal conductivity

DLW MODE DESCRIPTION

- Allowed modes are longitudinal section magnetic/electric (LSM/LSE)
- Lowest accelerating mode is LSM_{11}



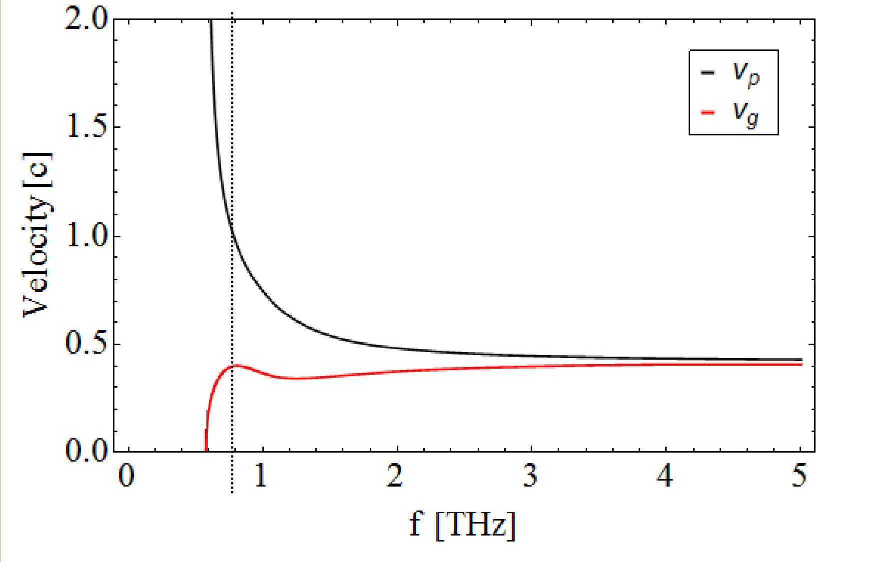


- Capable of constant acceleration over the length of the structure at a single frequency.
  - Range of frequencies provide constant acceleration – describe this as the accelerating bandwidth. This is the range of frequencies which slip out of phase with an electron by $< \pm \pi/2$ over the length of the structure.

DLW MODE DESCRIPTION

For constant acceleration and constant field amplitude, want both $v_p = c$ and $v_g = c$. This isn't the case!

The THz pulse will propagate slower than the electron and will experience a decreasing field amplitude.



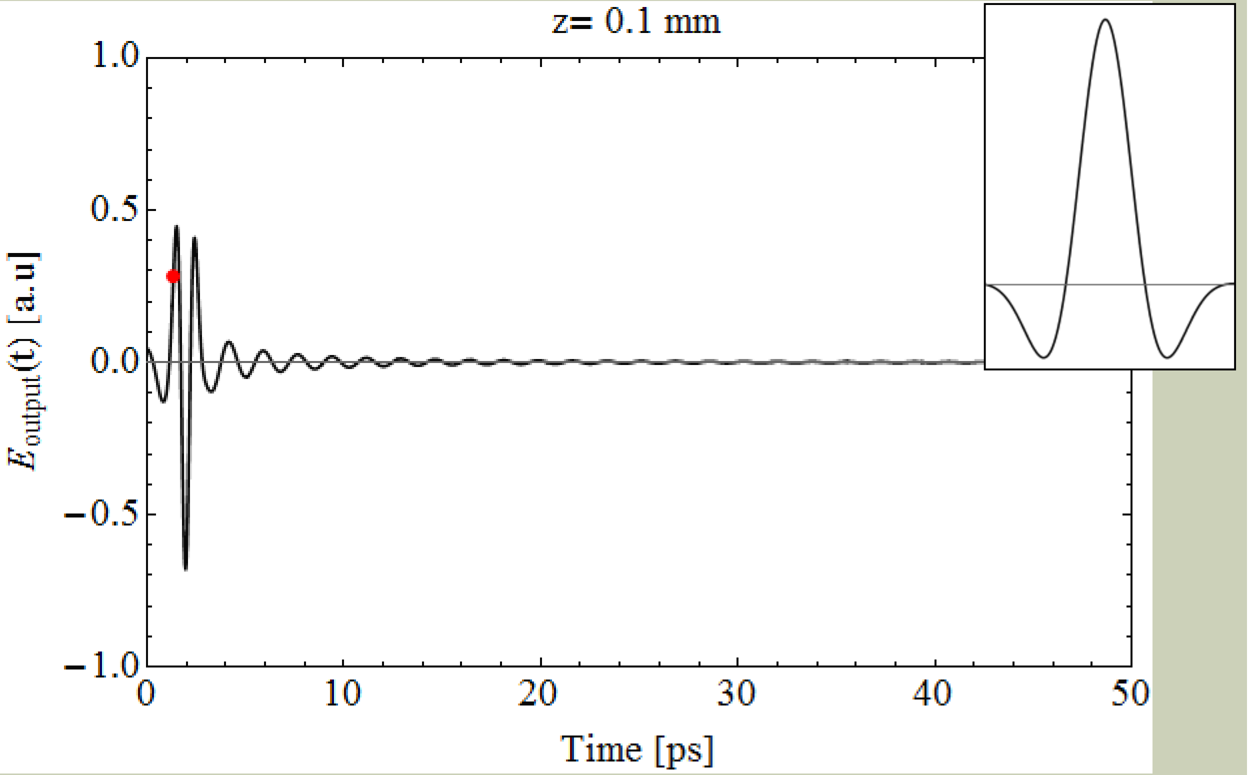
Dimension	Size (μm)
Waveguide width, w	600
Dielectric slab separation, 2a	200
Dielectric slab thickness, t	30
Waveguide length, L	10000

Operating frequency **0.784 THz**

Accelerating bandwidth **10 GHz**

THZ SOURCE DESCRIPTION AND PULSE PROPAGATION

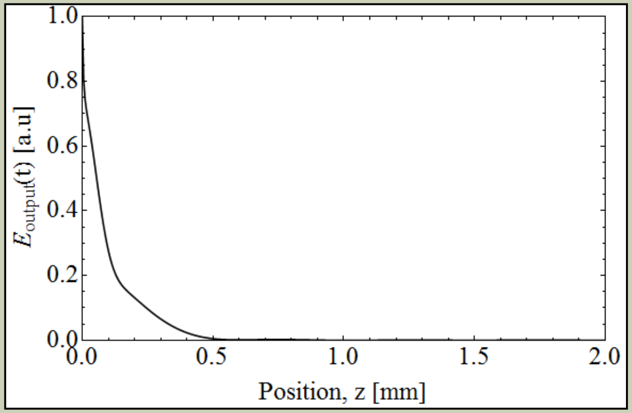
- Pulse propagation in DLW can be described using Fourier optics
- Pulse envelope travels slower than electron
- Can be mitigated with multi-cycle pulse



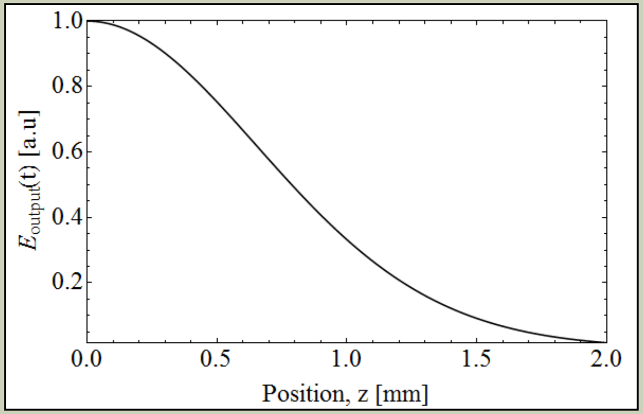
$$E_{output}(z,t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} E_{input}(t)e^{-i[\omega t - \beta(\omega)z]}d\omega$$

THZ SOURCE DESCRIPTION AND PULSE PROPAGATION

- Pulse propagation in DLW can be described using Fourier optics
- Field amplitude at operating frequency decreases with position



Single-cycle pulse

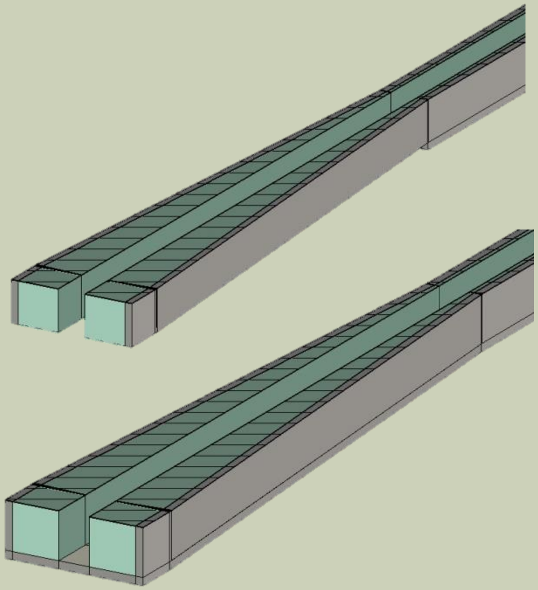


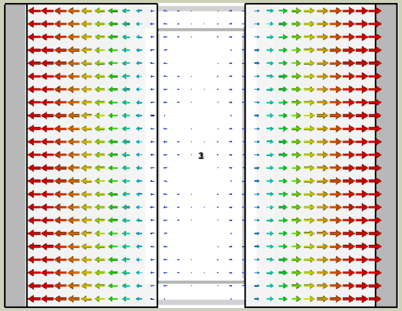
Ten-cycle pulse

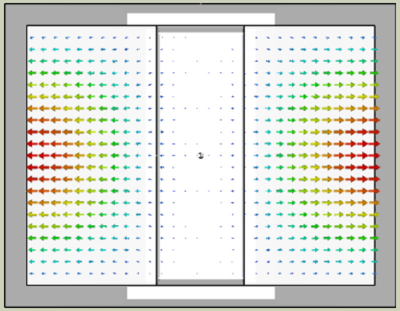
$$E_{output}(z,t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} E_{input}(t)e^{-i[\omega t - \beta(\omega)z]}d\omega$$

COUPLER DESIGN

- A coupler is necessary to guide the free-space THz pulse into the DLW
- Focus on the use of two dielectric waveguides which taper down into the structure







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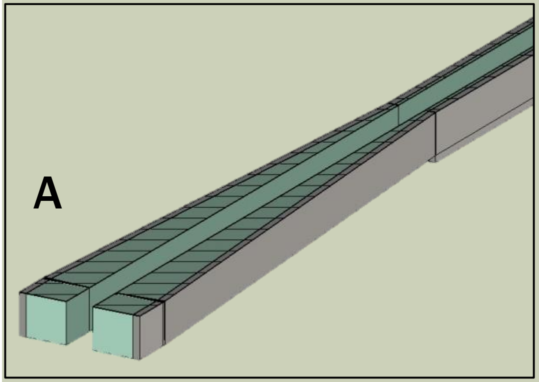
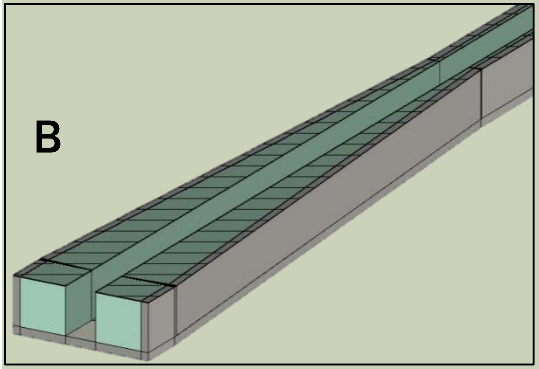
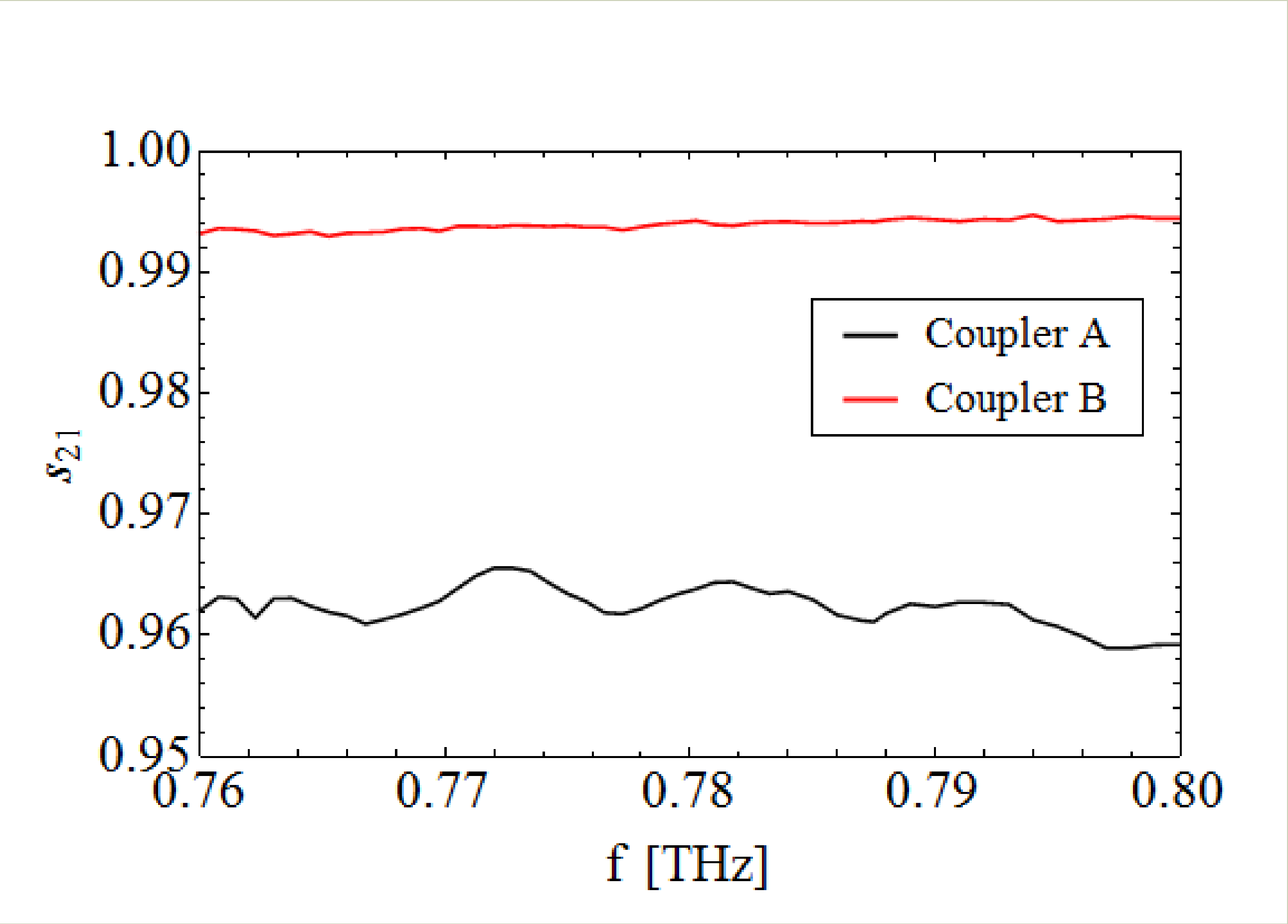
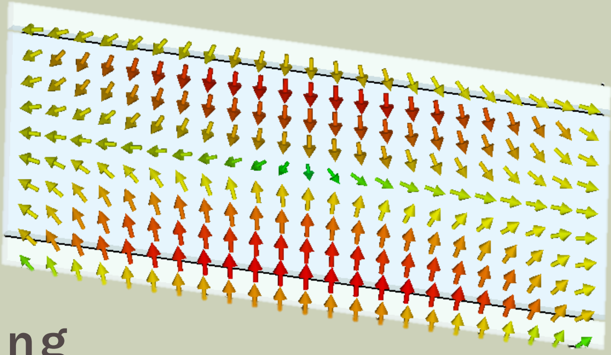


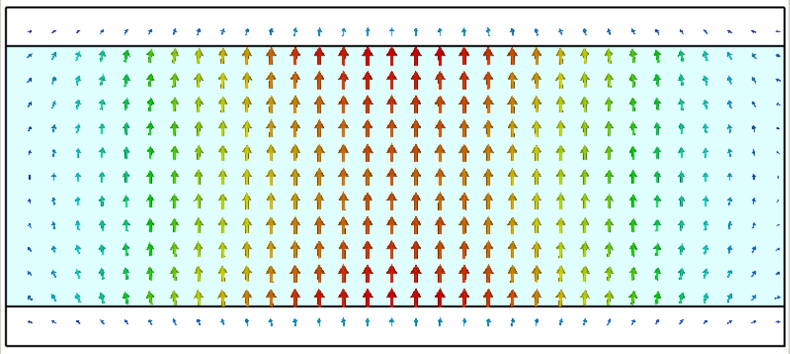


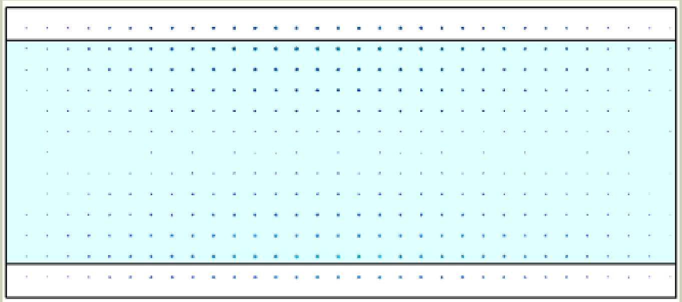


ELECTRON MANIPULATION

- Accelerating mode (LSM_{11}) operated at a $\pi/_{2}$ phase shift behaves similar to a quadrupole.
  - Array of DLWs rotated alternatively by $90°$ would act similar to a FODO lattice.
  - Useful for focussing
- Lowest order mode (LSM_{10}) is a deflecting mode
  - Uses in beam diagnostics







EXPERIMENTAL PLANS

- CVD diamond will be fabricated in-house
  - Investigate CVD diamond properties at THz frequencies
- Off-beam structure testing
  - Compare with simulations
  - Test tuneable structure
- Non-relativistic electron acceleration
  - 60keV electron gun at the University of Manchester
- Plans to use the VELA/CLARA beam in 2017