ELECTRON-THZ INTERACTION IN DIELECTRIC-LINED WAVEGUIDE DEFLECTING STRUCTURES

A.L. Healy, G. Burt, S.P. Jamison
The Cockcroft Institute, Sci-Tech Daresbury, Warrington, WA4 4AD, UK
Lancaster University, Engineering, Lancaster, LA1 4YR, UK
alisa.healy@cockcroft.ac.uk

Terahertz-driven dielectric-lined waveguides (DLWs) have uses in electron manipulation; in particular deflection, acceleration, and focussing. A rectangular DLW has been optimised for deflection of 100 keV electrons using a THz pulse with a centre frequency 0.5 THz. A narrowband THz pulse is generated using a lithium niobate crystal and chirped pulse beating. Electron-THz interaction and the effect of electron bunch injection timing on maximising deflection is presented, with a focus on beam dynamics. Structure design, including coupling from free-space into the DLW, has been completed and the practical aspects of operation are discussed. Finally DLWs and corrugated waveguides are compared to discuss relative advantages and disadvantages.

Terahertz-driven dielectric-lined waveguides

DLW accelerators are considered as an alternative to rf accelerating structures due to:

- Potential for high accelerating gradients
- Wave can propagate with phase velocity $v_p \leq c$
- Simple designs in the THz-driven regime.

Fig. 1 shows a rectangular DLW. Short THz pulses are preferable over radio frequencies to improve accelerating gradients as field $E_s \propto f^{1/2}\tau^{-1/4}$ [1].

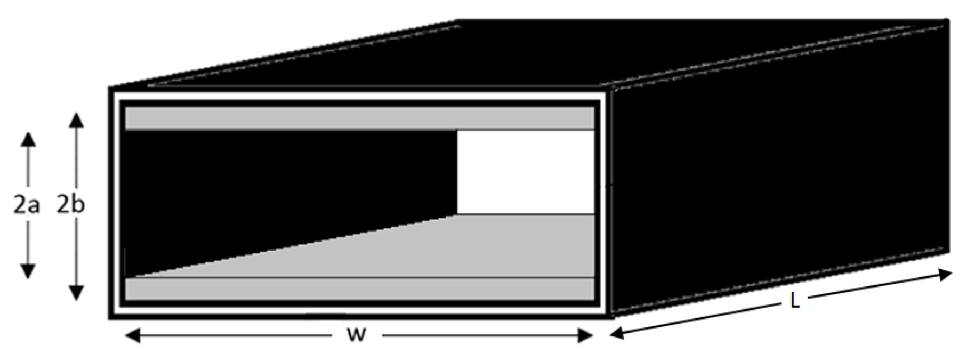


Figure 1: Rectangular DLW. The thickness of the dielectric is given by $t = b - a$.

Corrugated waveguides

Corrugated waveguides are another design option, shown in Fig. 2.

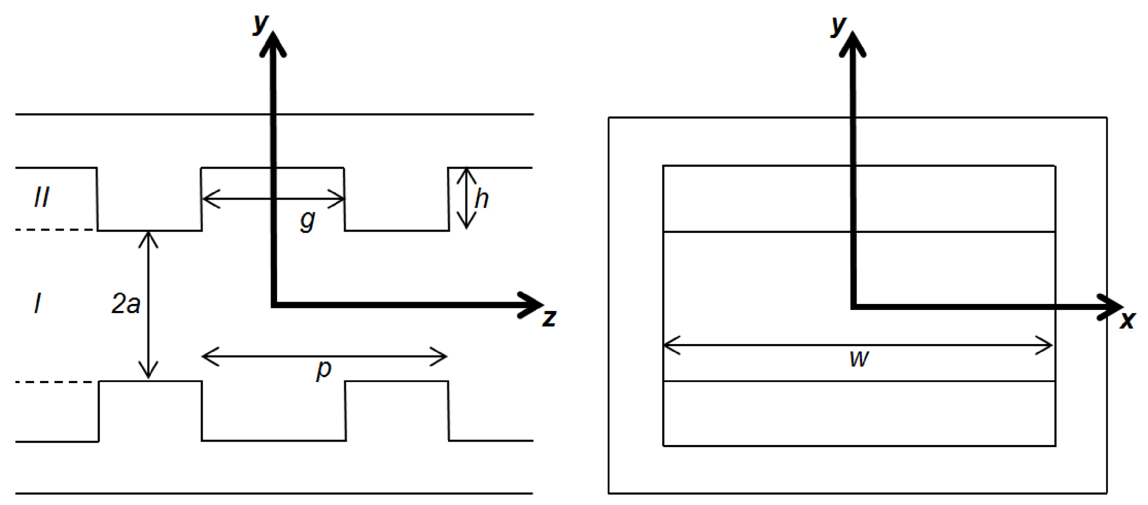
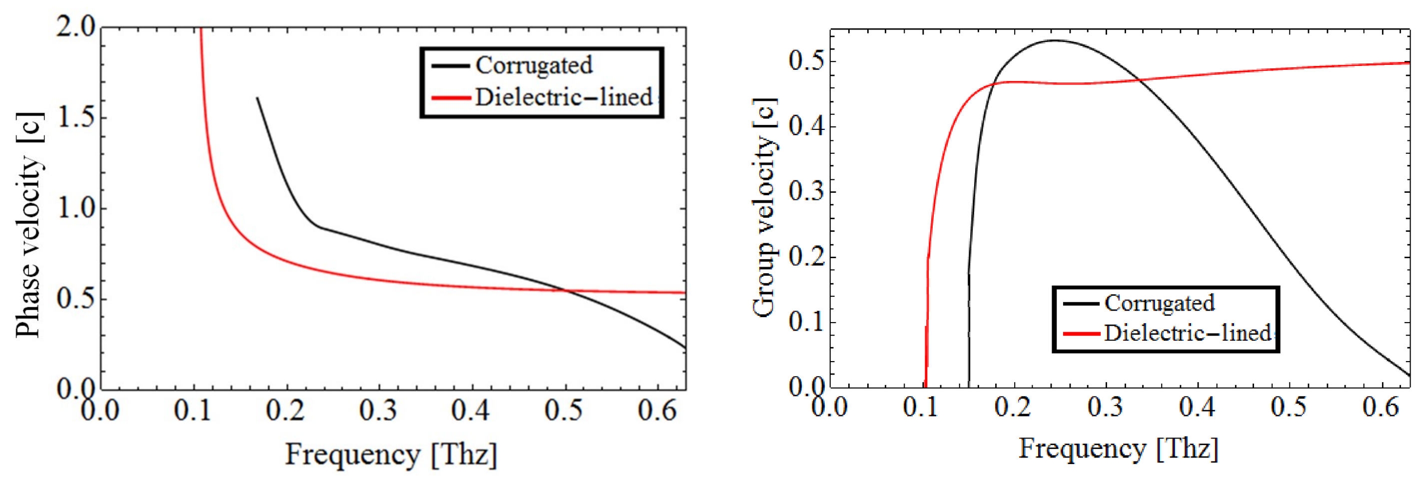


Figure 2: Corrugated rectangular waveguide. Left: side view, right: cross-sectional view.

Corrugations allow $v_p \leq c$. Comparisons of v_p and v_g for 100keV electron interaction are shown in Fig. 3 for a deflecting waveguide operating at 0.5 THz.



Figures 3,4: Phase and group velocity of corrugated waveguide and DLW.

Corrugated waveguides are preferable for higher transverse voltage at the operating frequency, but low v_g means short interaction length. Transit time factor is included in V_t calculations., shown in Fig. 5.

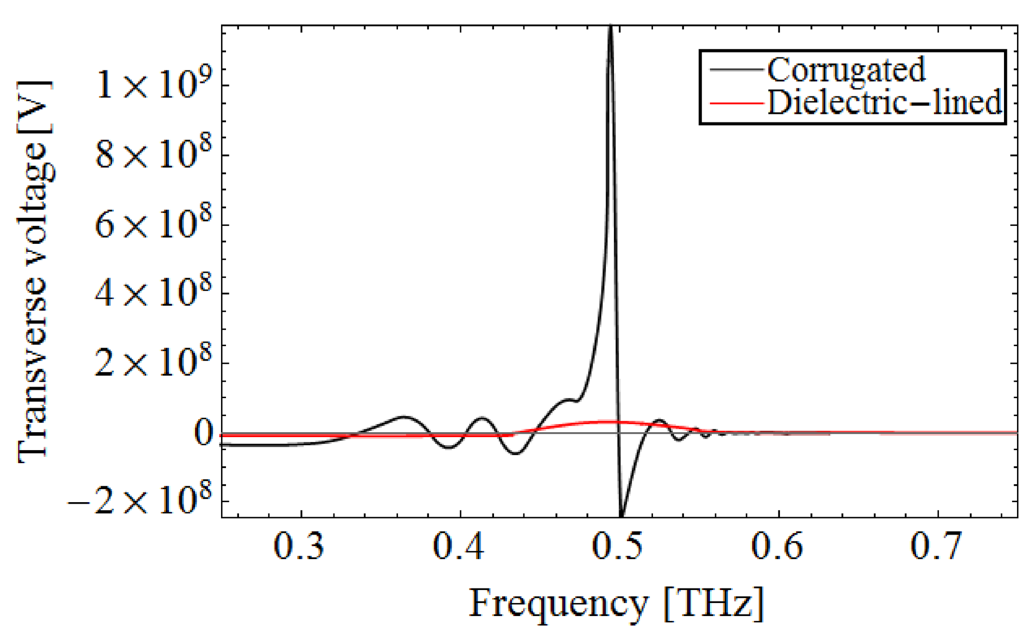


Figure 5: Transverse voltage as a function of frequency, including the transit time factor.

THz-electron interaction

The DLW can be driven by a THz pulse of any chosen length. The most easily generated pulse is single-cycle (wide bandwidth). The resultant y-momentum at a given time is shown in Fig. 6. This is compared with a ten-cycle cycle pulse in Fig. 8. Interaction with the THz is not linear, but in the case of a single-cycle pulse the interaction is not constant – electrons do not appear to co-propagate with the THz pulse at the same phase velocity.

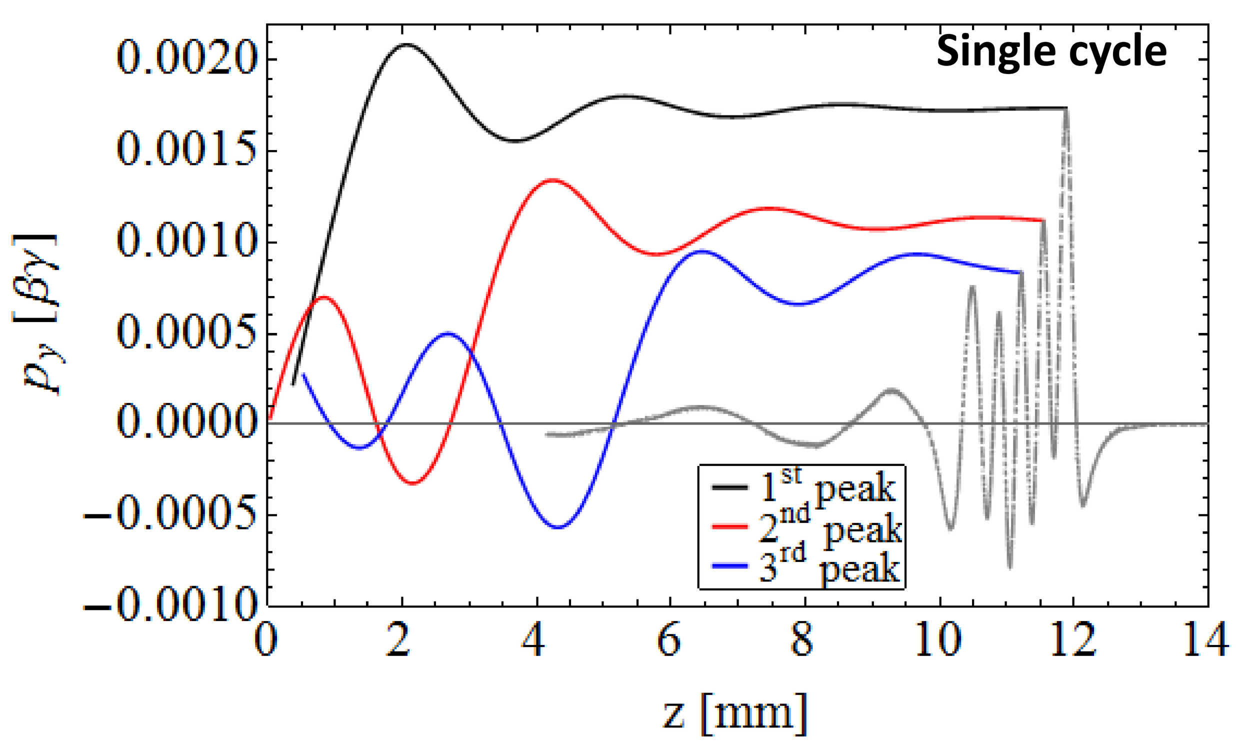
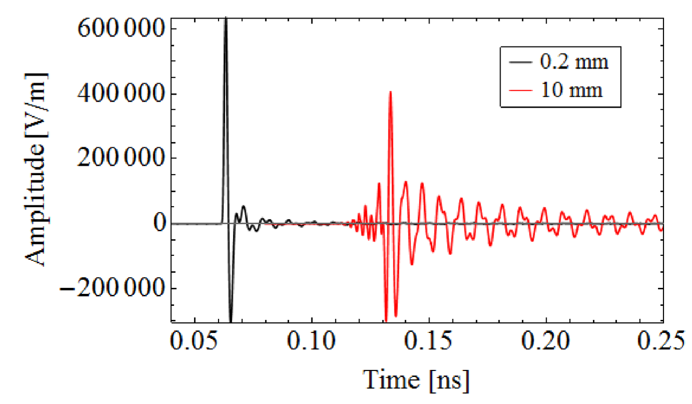


Figure 6: Grey; y -momentum of particles in a bunch taken as a snapshot along the propagation axis. Black, blue, red; THz-electron interaction of a single electron along the waveguide.

Figure7: Amplitude of pulse at start and end of DLW.



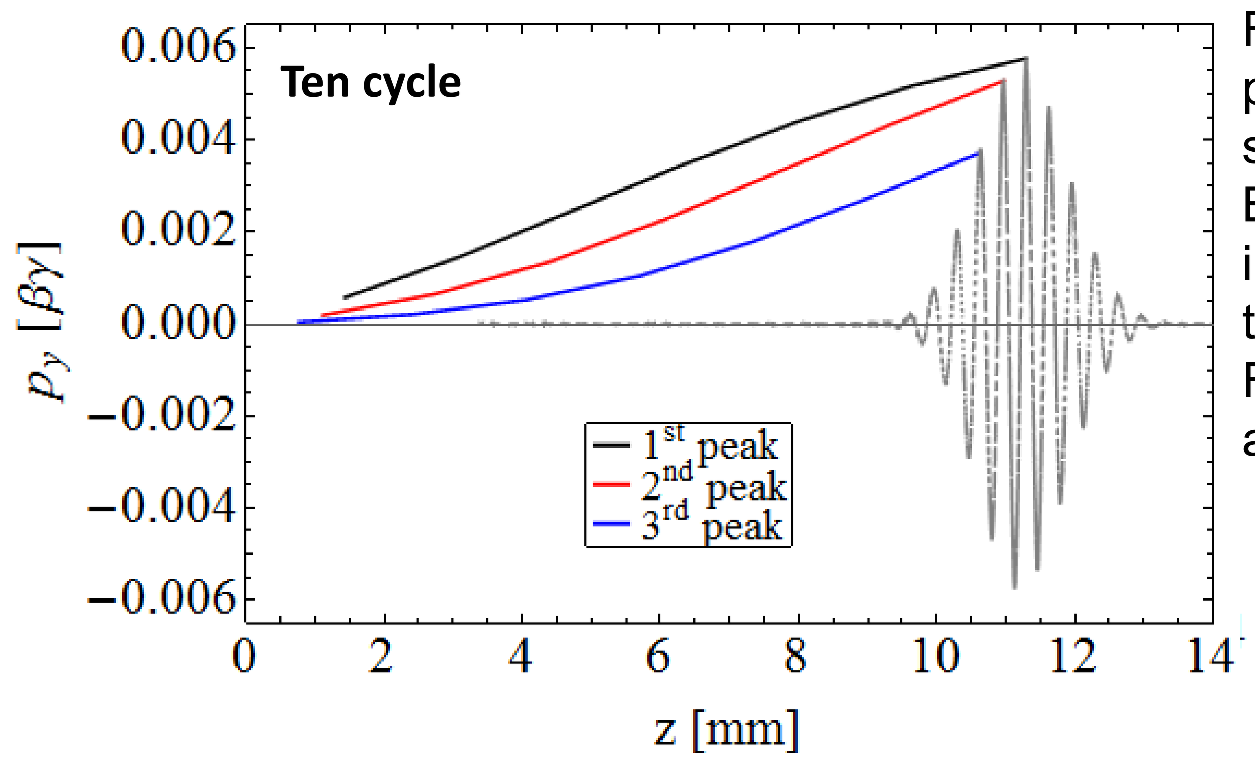
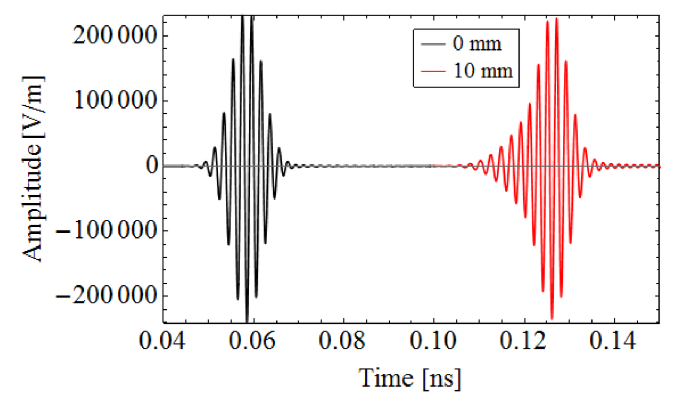


Figure 8: Grey; y-momentum of particles in a bunch taken as a snapshot along the propagation axis. Black, blue, red; THz-electron interaction of a single electron along the waveguide.

Figure 9: Amplitude at pulse at start and end of DLW.



Practical considerations

A coupler is required to guide a THz pulse with a transverse $5x10$ mm spot size into the $0.2x1$ mm waveguide. The coupler is metallic with no dielectric. Dispersion caused by the coupler is noticeable for 10-cycle pulses but the overall pulse shape is preserved. Figs. 9 and 10 show the coupler dispersion for single- and ten-cycle THz pulses.

The bottom half of the manufactured structure is shown in Fig. 11.

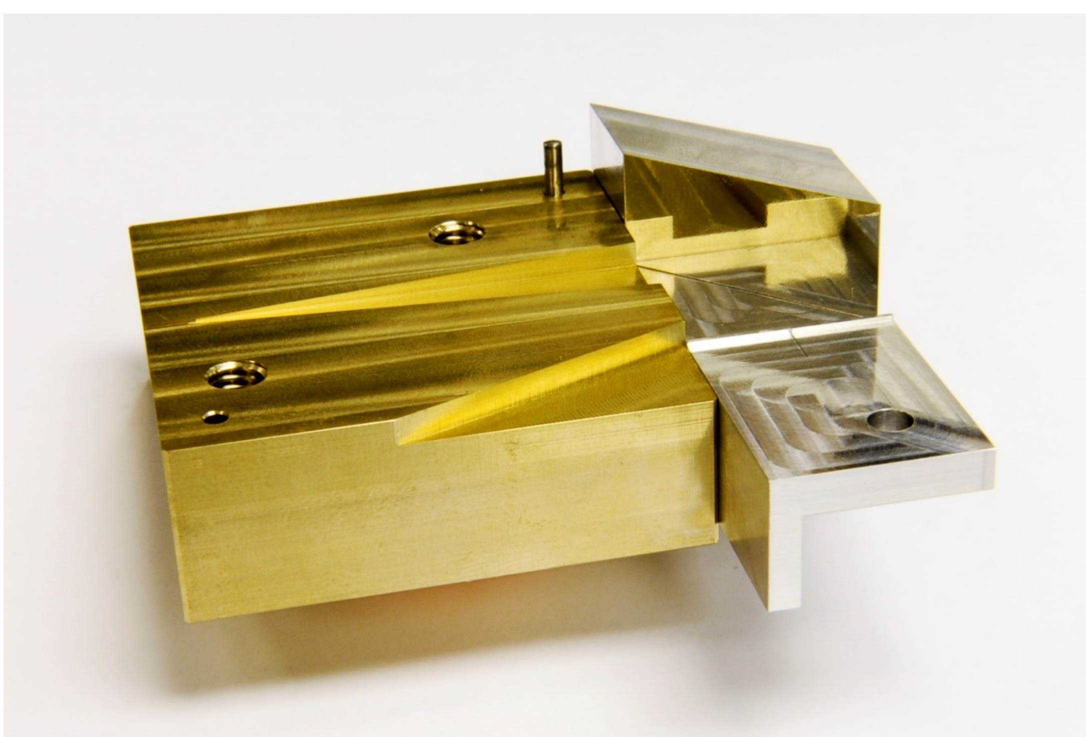
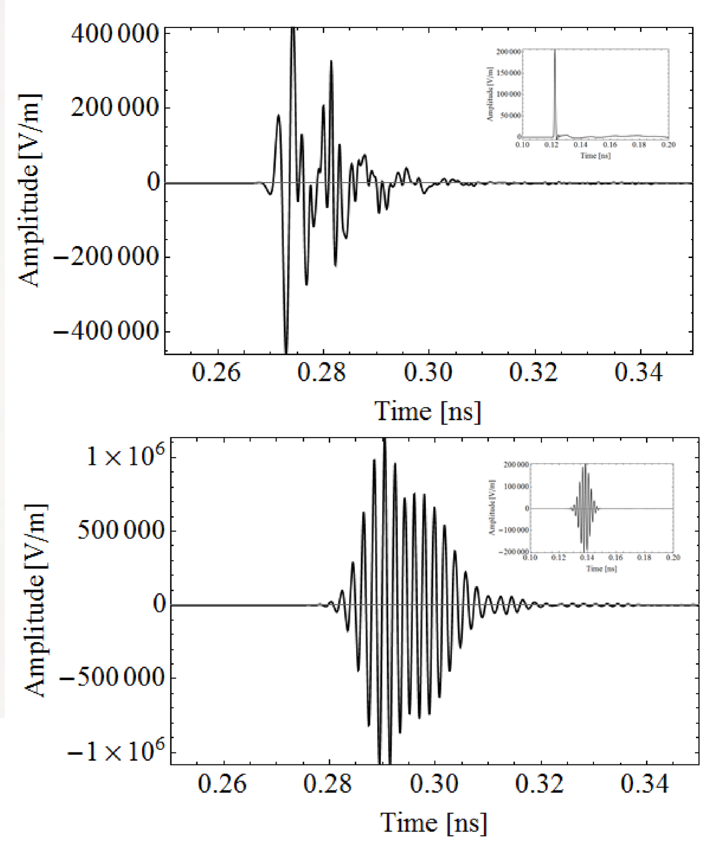


Figure 11: Bottom half of the full DLW structure, including crystal shelf and mirror.



Figures 9,10: THz pulse dispersion at the end of the coupler for single- and ten-cycle THz pulses.

Conclusions and future outlook

A dielectric-lined waveguide has been designed and manufactured for deflection of 100 keV electrons. The effect of THz input pulse length on electron interaction has been studied to choose the optimal pulse for maximised deflection.

An analogous corrugated waveguide has been shown to be favourable for ultra narrowband pulses, however manufacturing requires more precise tooling which is not as readily available.

References: : **[1]** Lowe, G.A. et al., SLAC-PUB-4647, 1988

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