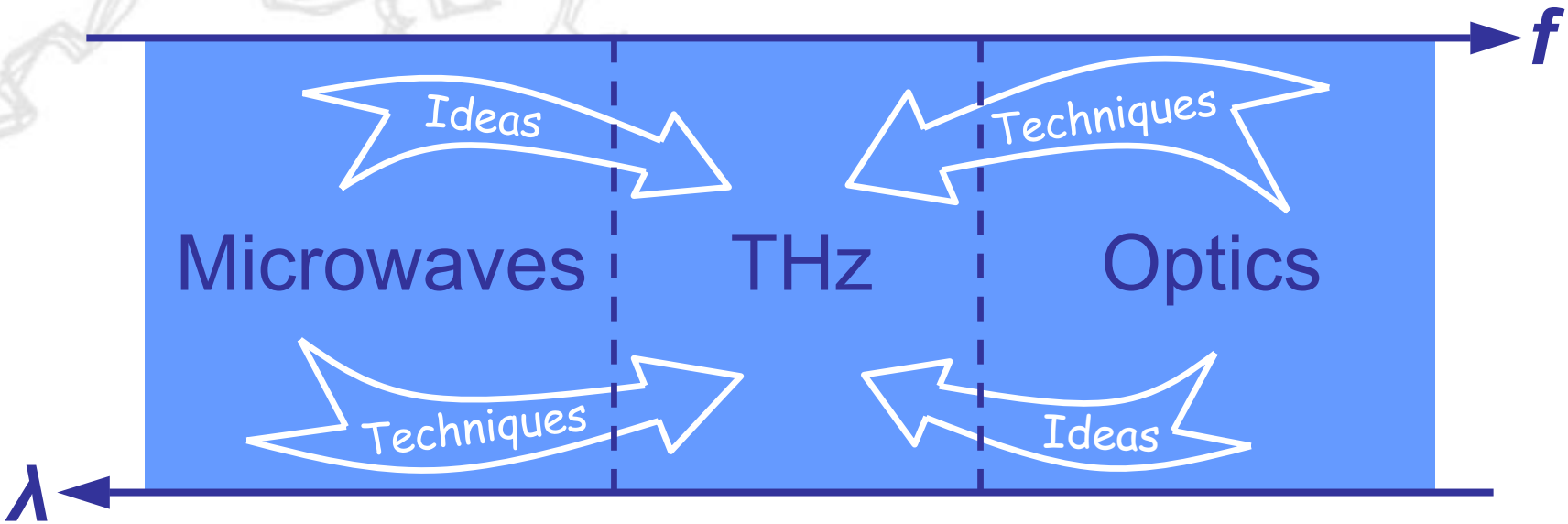
THz Waveguides: The Evolution

Rajind Mendis

University of Wollongong, Australia

“Chronological” series of experimental investigations into the guided-wave propagation and the associated coupling of THz pulses

Approach……


f
Ideas
Techniques
Microwaves
THz
Optics
Techniques
Ideas
λ

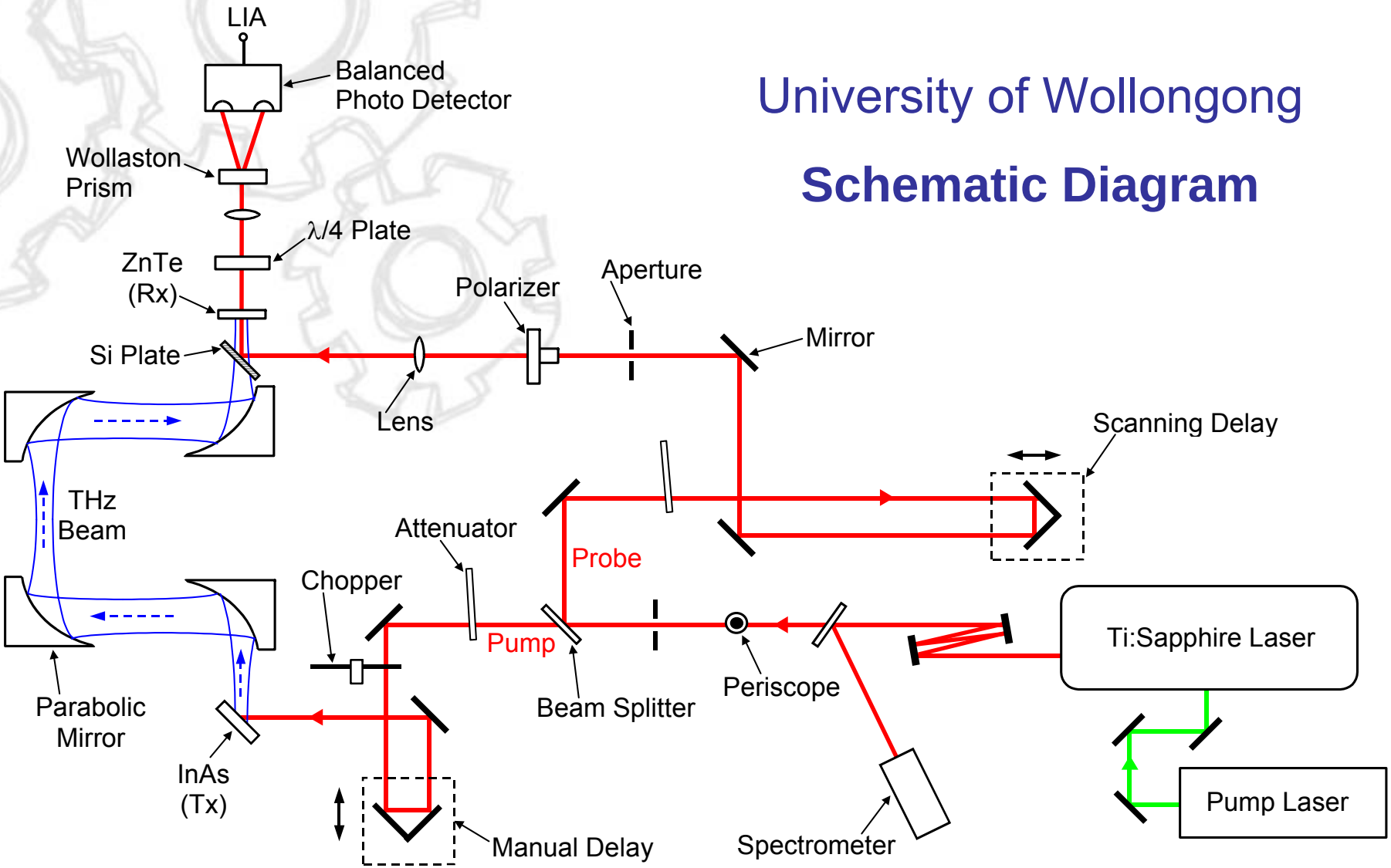
Outline

- THz-TDS System
- Incorporating the Waveguide
- Important Considerations
- Waveguides……
- Guided-Wave THz-TDS

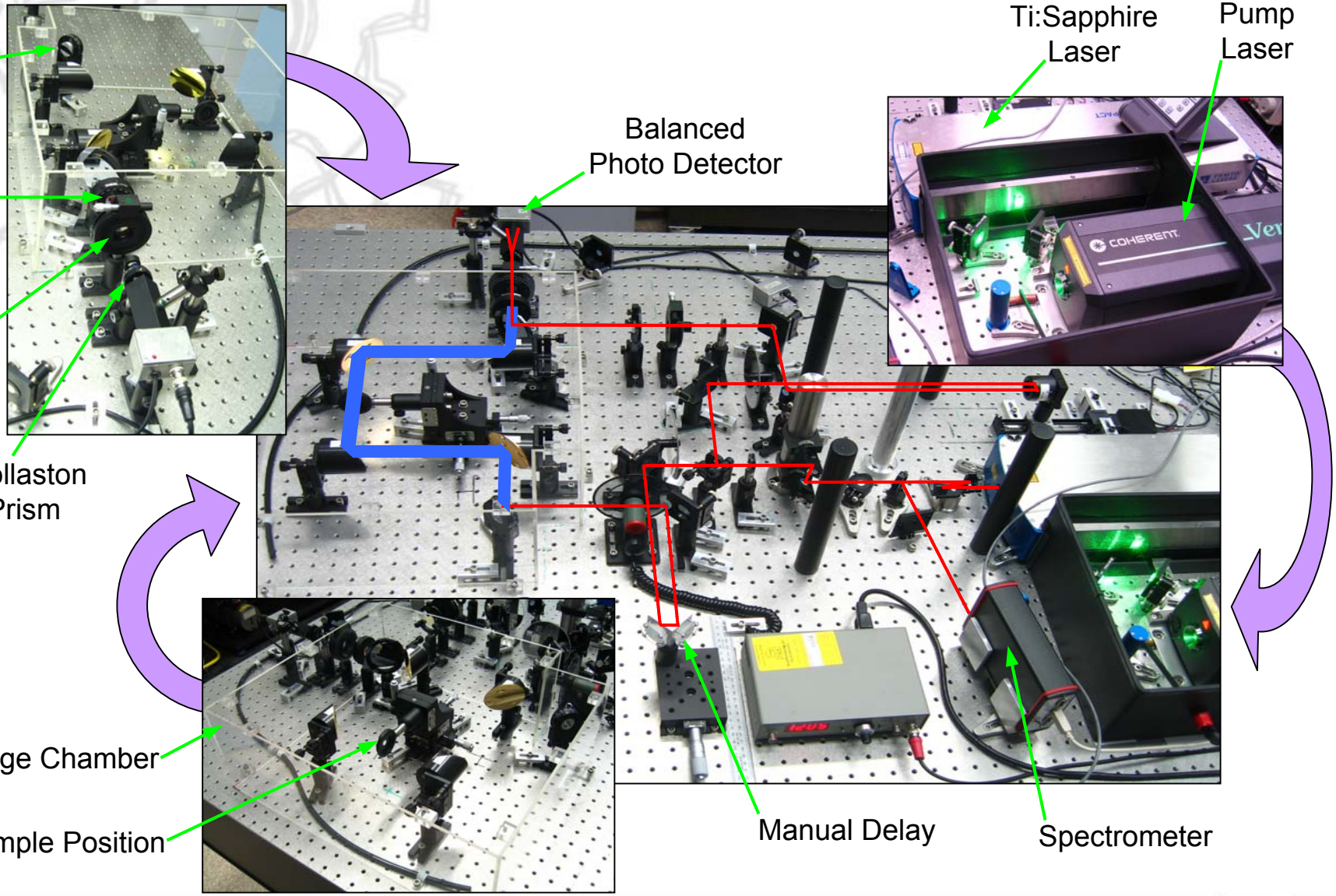
THz-TDS System

University of Wollongong

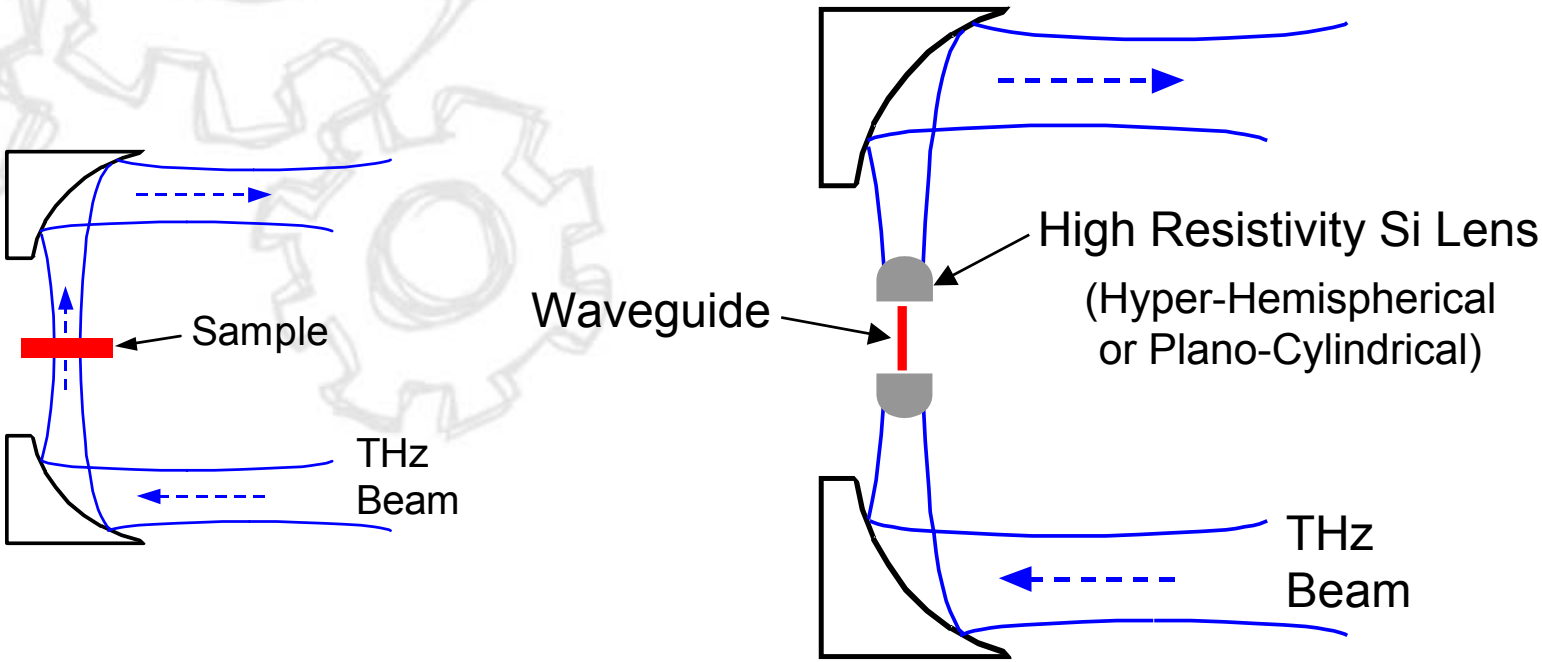
Schematic Diagram



THz-TDS System



Incorporating the Waveguide

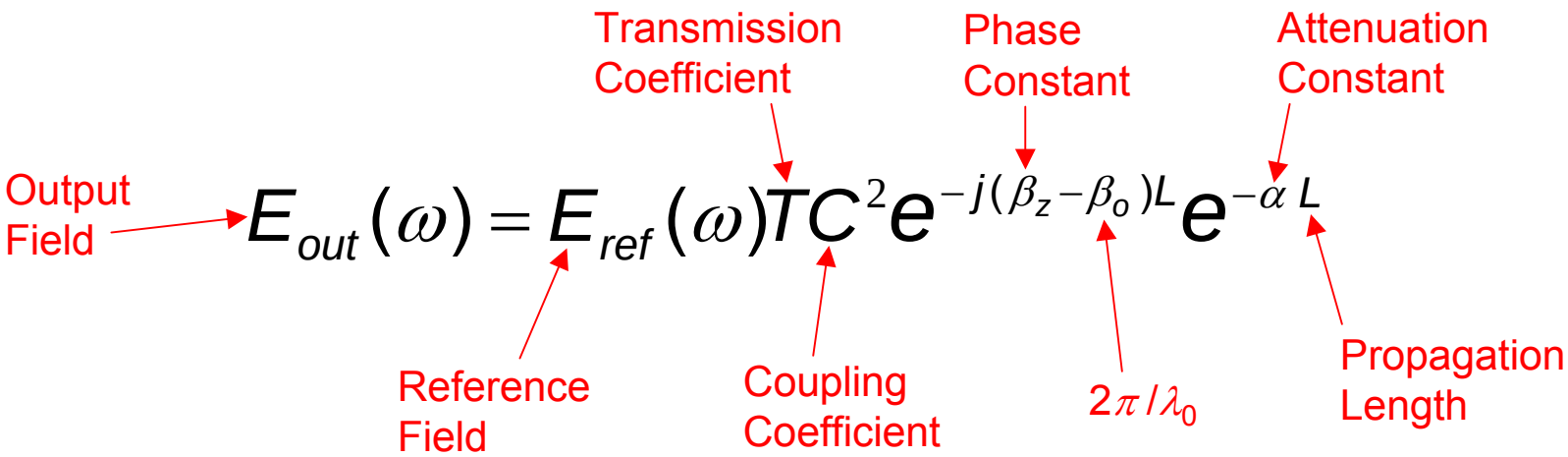


Quasi-Optic Coupling

Sample ≡ Lens-Waveguide-Lens

Important Considerations

- Attenuation
- Dispersion – Group-Velocity (v_g)
- Input/Output Coupling – Mode-Matching
- Single-Mode Propagation



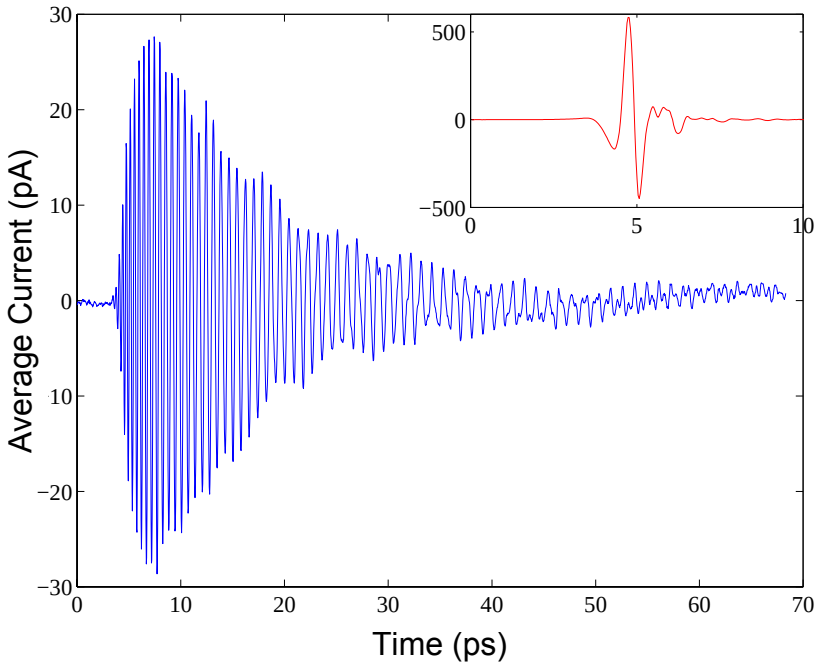
Waveguides……

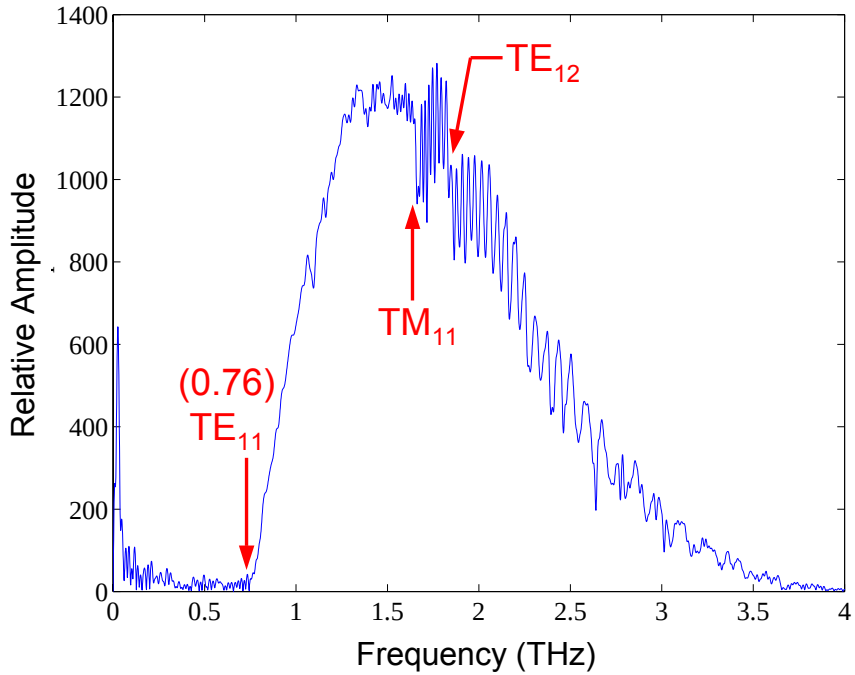
Hollow Metallic Circular Waveguide

Stainless Steel

240 μm diameter

24 mm long





Negative Chirp

1ps ➞ 70 ps !

Multi-Mode

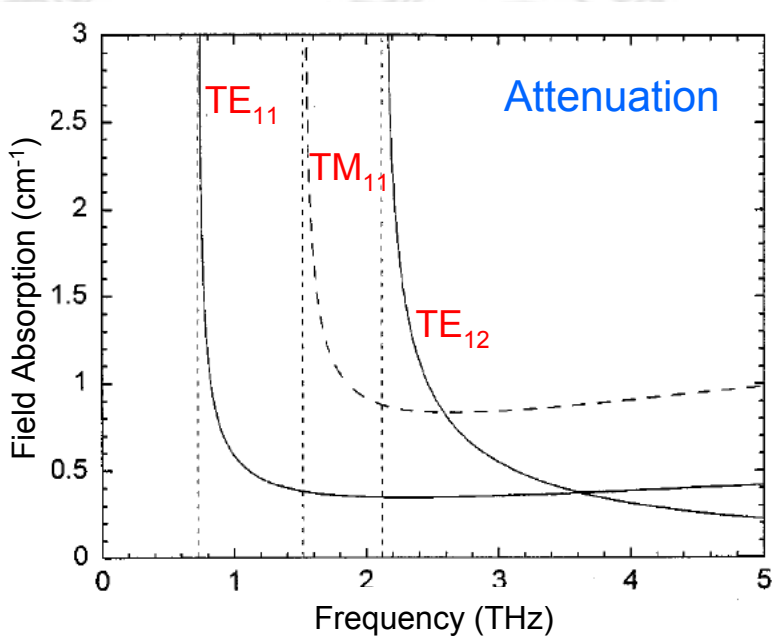
R. W. McGowan, G. Gallot, D. Grischkowsky
Opt. Lett. 24, 1431 (1999)

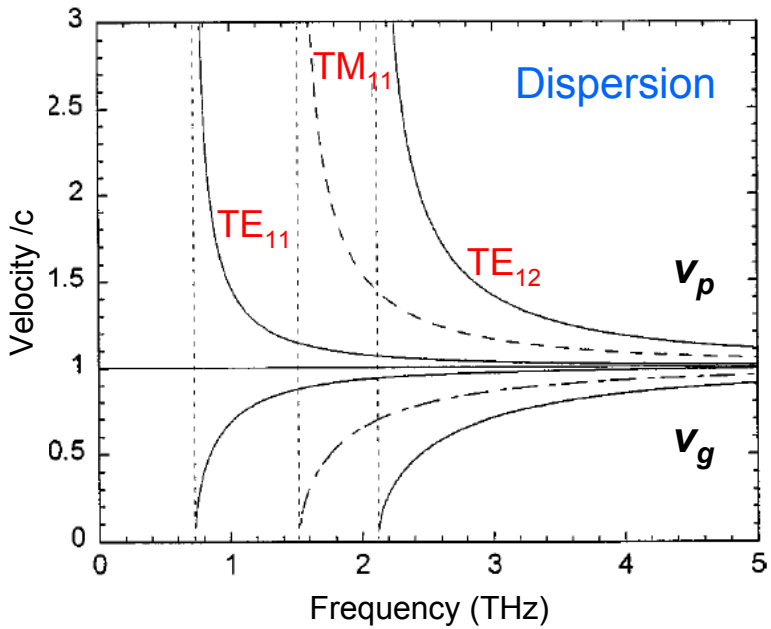
Hollow Metallic Circular Waveguide

Stainless Steel

240 μm diameter

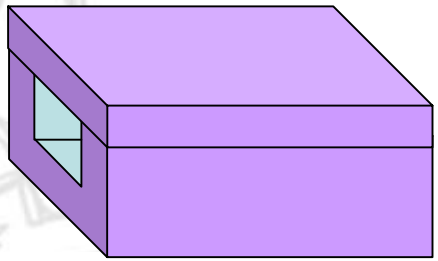
24 mm long





G. Gallot, S. P. Jamison, R. W. McGowan, D. Grischkowsky
J. Opt. Soc. Am. B 17, 851 (2000)

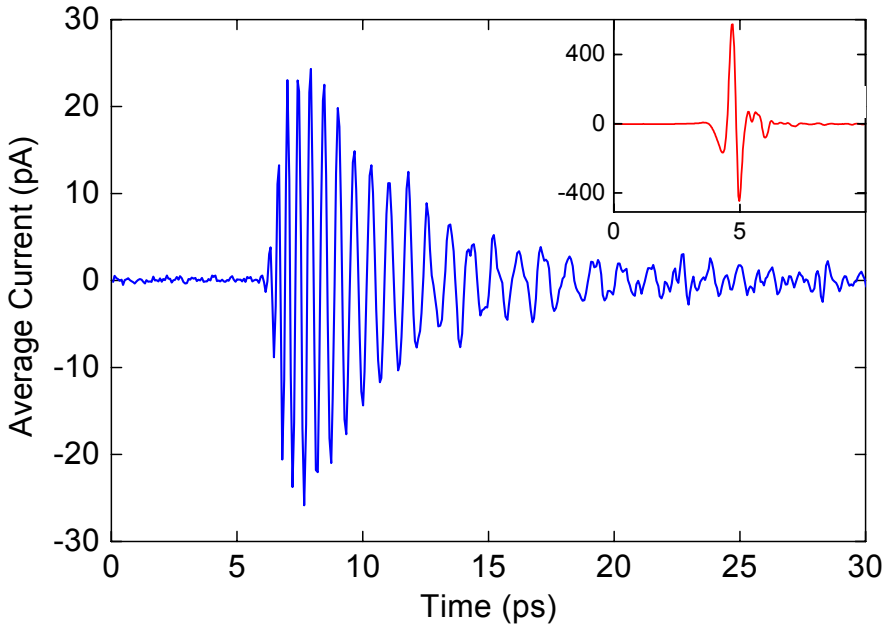
Hollow Metallic Rectangular Waveguide

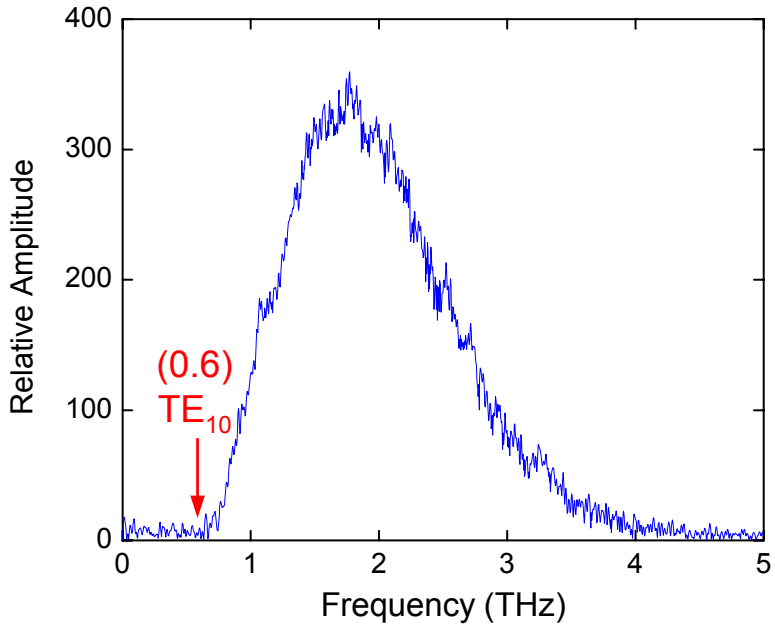


Brass

250 μm × 125 μm

25 mm long





Negative Chirp

1ps ➞ 25 ps

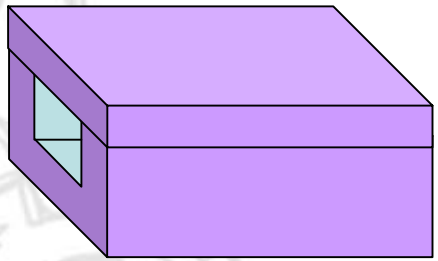
"Effectively"

Single-Mode (TE_{10})

G. Gallot, S. P. Jamison, R. W. McGowan, D. Grischkowsky

J. Opt. Soc. Am. B 17, 851 (2000)

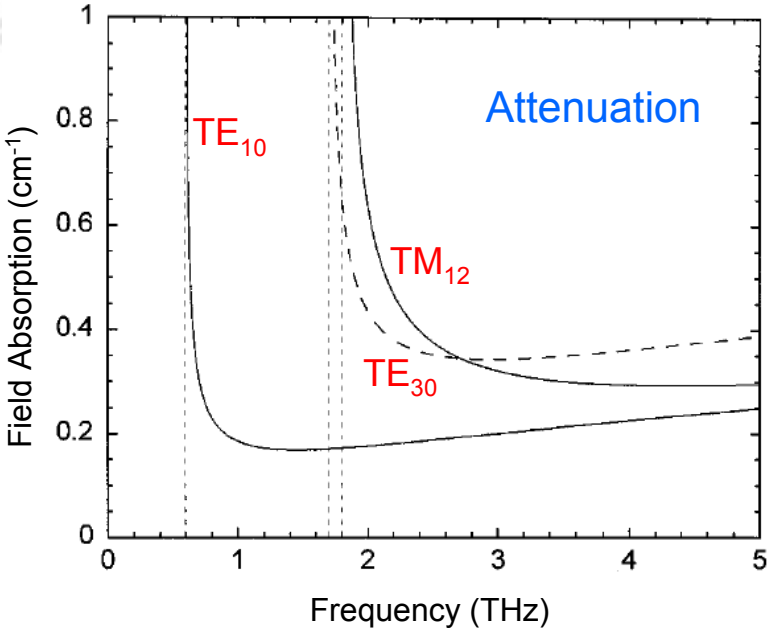
Hollow Metallic Rectangular Waveguide

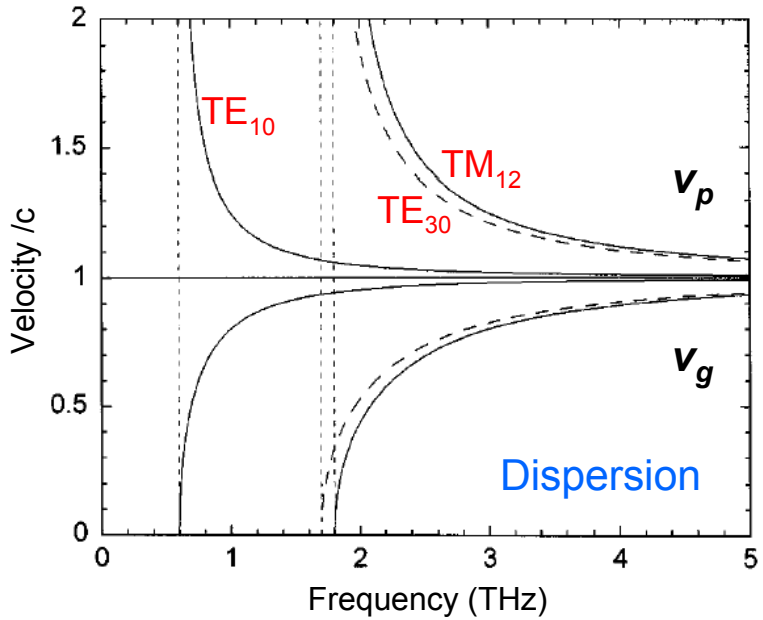


Brass

250 μm × 125 μm

25 mm long





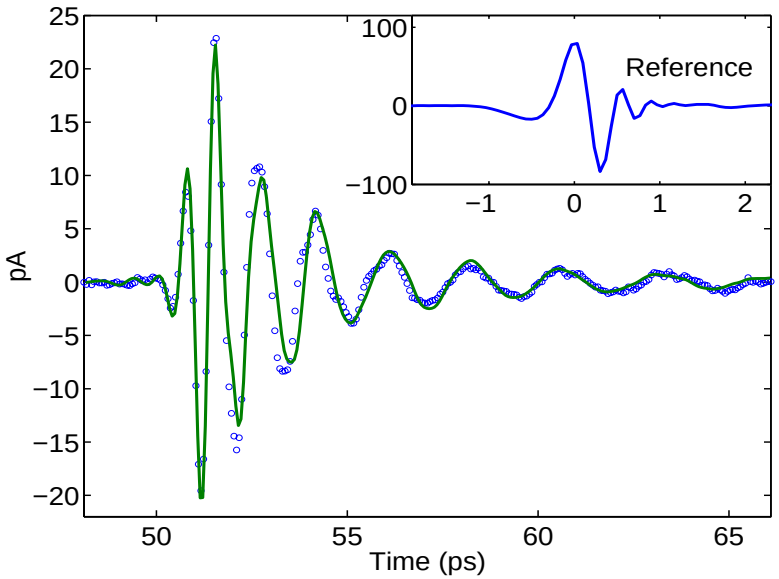
G. Gallot, S. P. Jamison, R. W. McGowan, D. Grischkowsky
J. Opt. Soc. Am. B 17, 851 (2000)

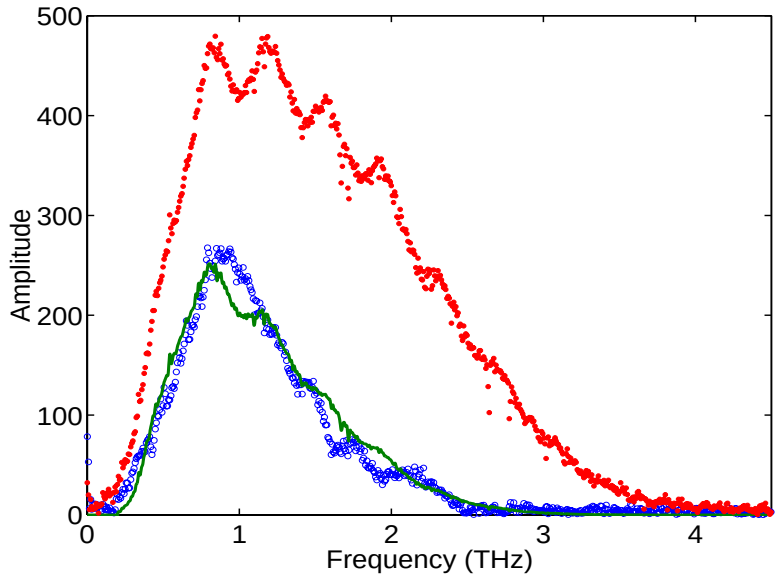
Dielectric Fiber

Single Crystal Sapphire

325 μm diameter

7.3 mm long





Negative Chirp

1ps ➞ 15 ps

Single-Mode (HE_{11})

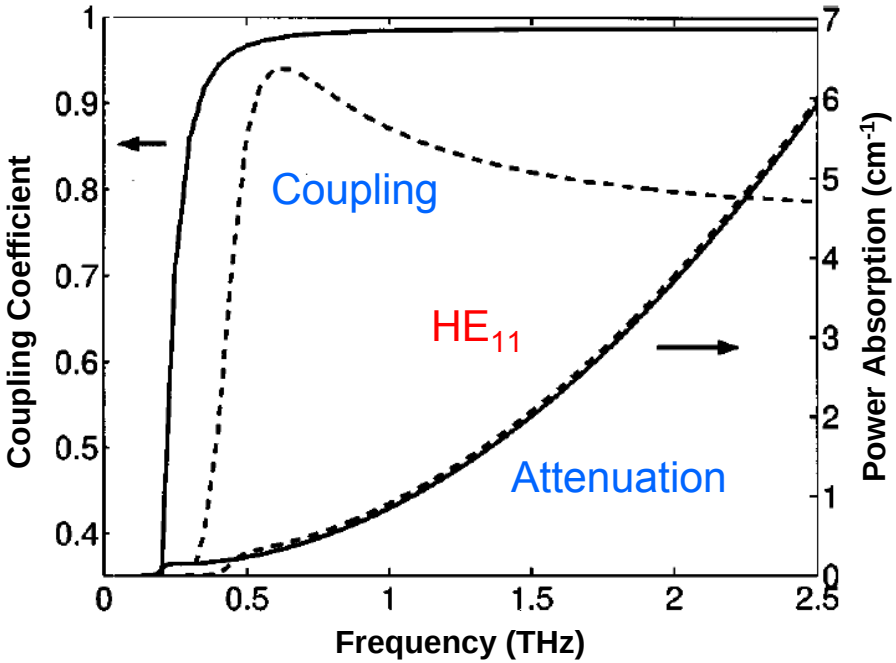
S. P. Jamison, R. W. McGowan, D. Grischkowsky
Appl. Phys. Lett. 76, 1987 (2000)

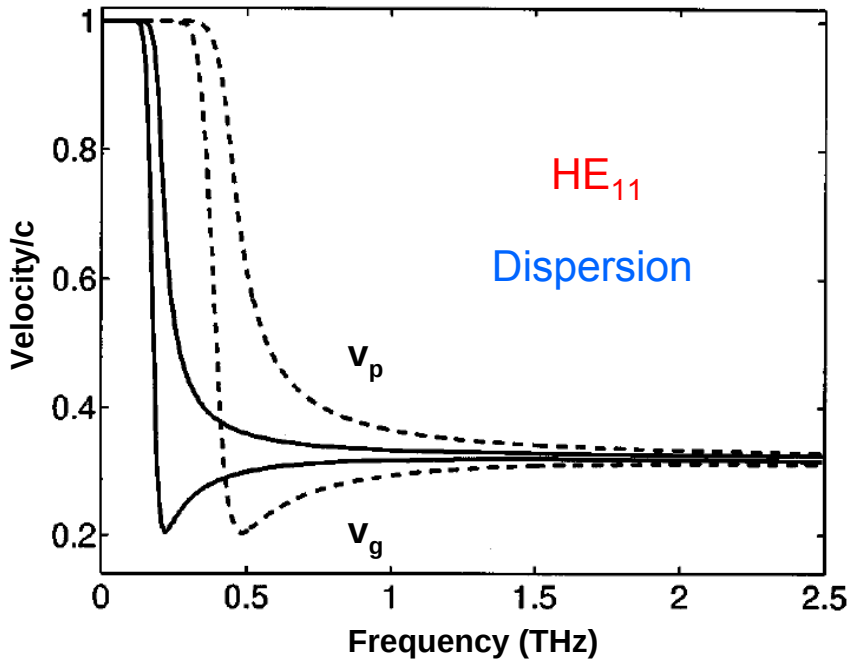
Dielectric Fiber

Single Crystal Sapphire

325 μm diameter

7.3 mm long

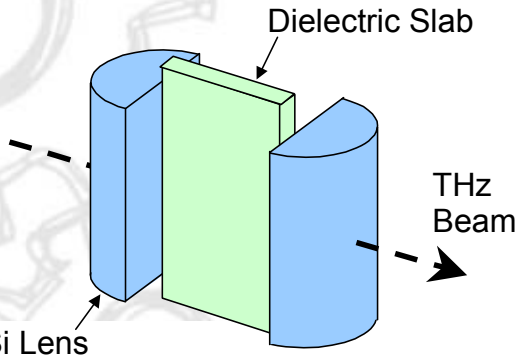




Dashed Lines – 150 μm dia.

S. P. Jamison, R. W. McGowan, D. Grischkowsky
Appl. Phys. Lett. 76, 1987 (2000)

Dielectric Slab (Plastic Ribbon)

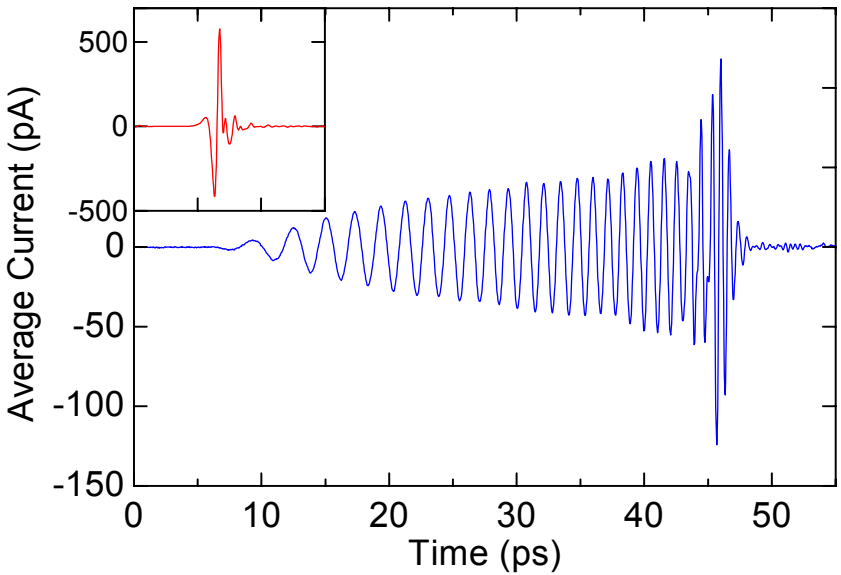


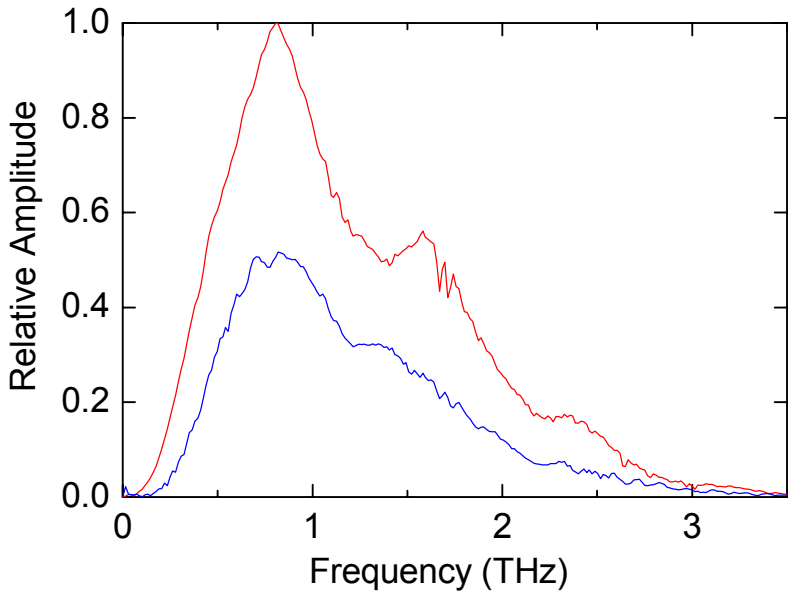
High Density Polythene

120 μm thick

20 mm long

20 mm wide





Positive Chirp

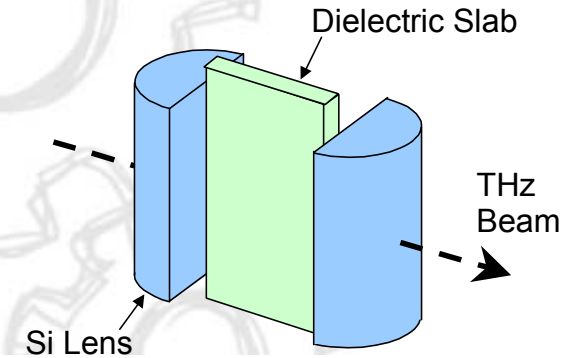
1ps ➞ 45 ps

Single-Mode (TM_0)

R. Mendis, D. Grischkowsky

J. Appl. Phys. 88, 4449 (2000)

Dielectric Slab (Plastic Ribbon)

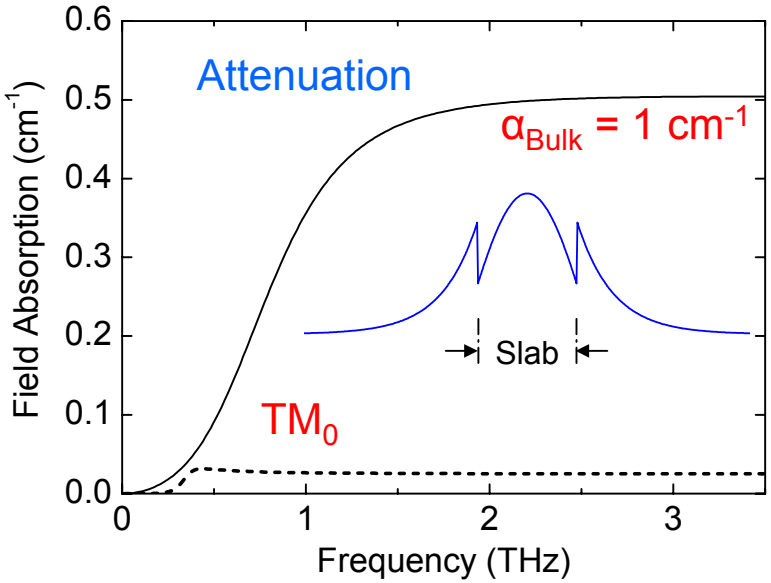


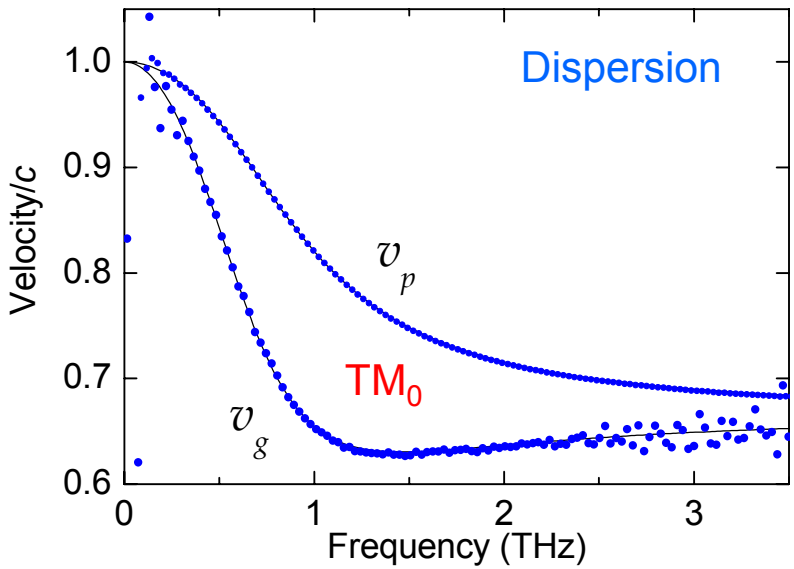
High Density Polythene

120 μm thick

20 mm long

20 mm wide

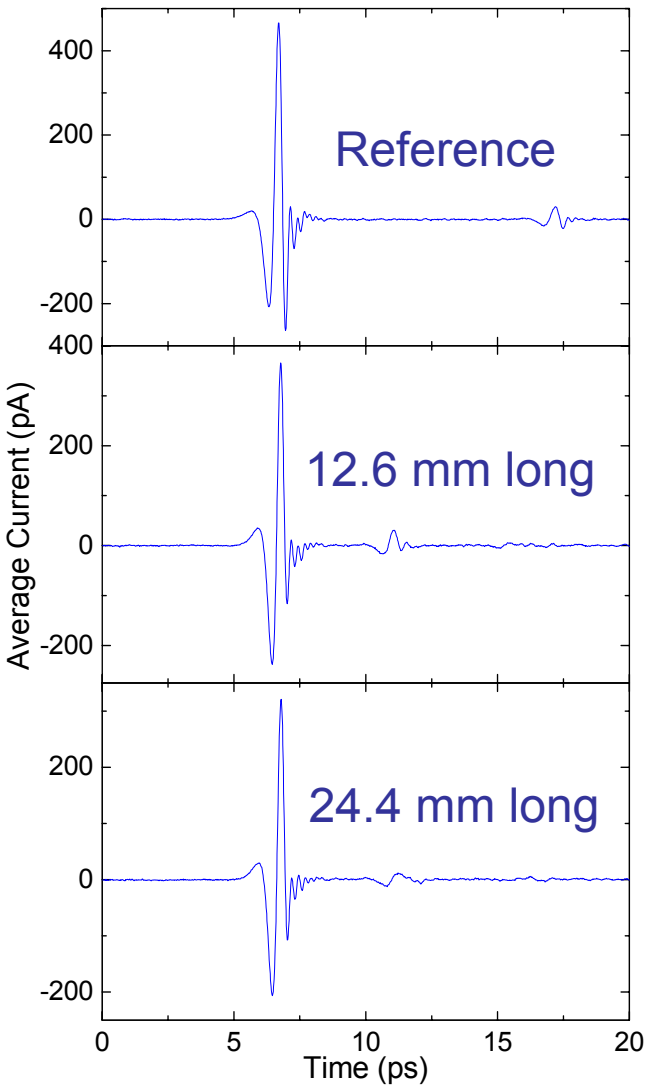


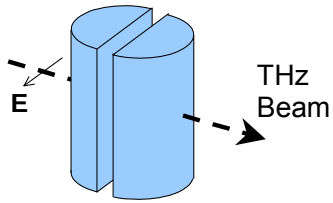


Dashed Line – High Resistivity Si (α_{Bulk} = 0.05 cm^{-1})

R. Mendis, D. Grischkowsky
J. Appl. Phys. 88, 4449 (2000)

Parallel-Plate Waveguide

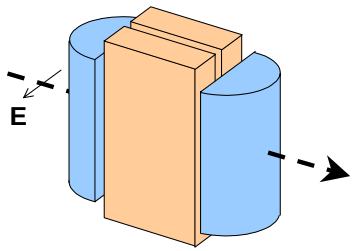




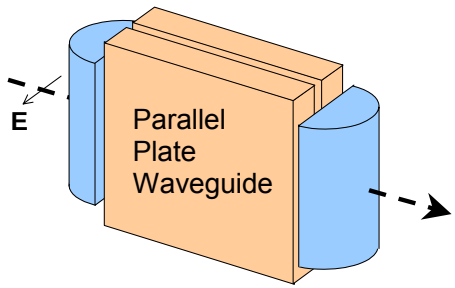
Copper

108 μm separation

20 mm wide



Undistorted propagation!!



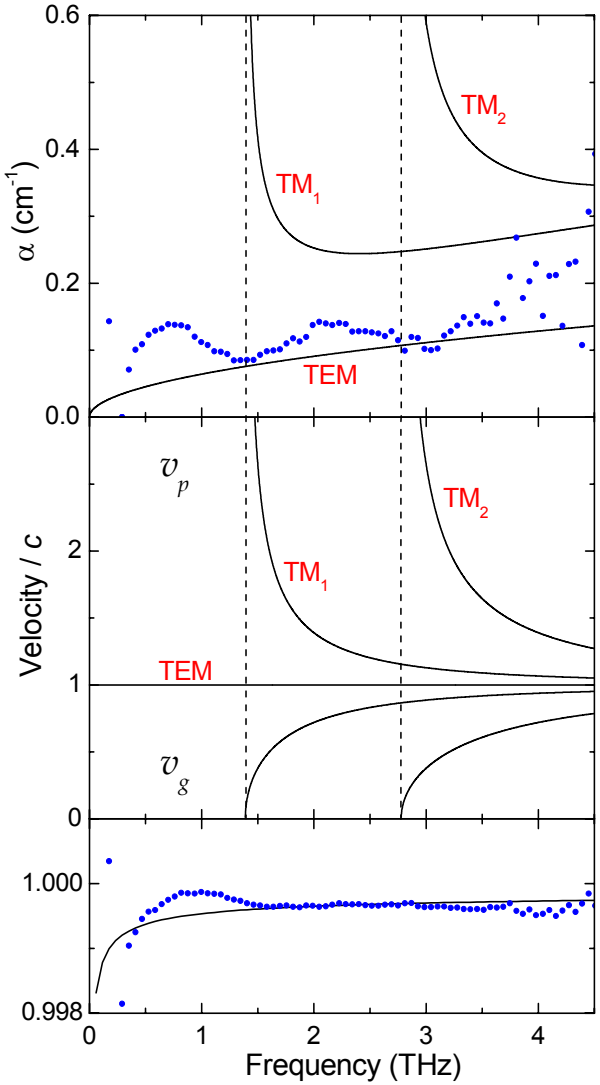
Single-Mode (TEM)

R. Mendis, D. Grischkowsky
Opt. Lett. 26, 846 (2001)

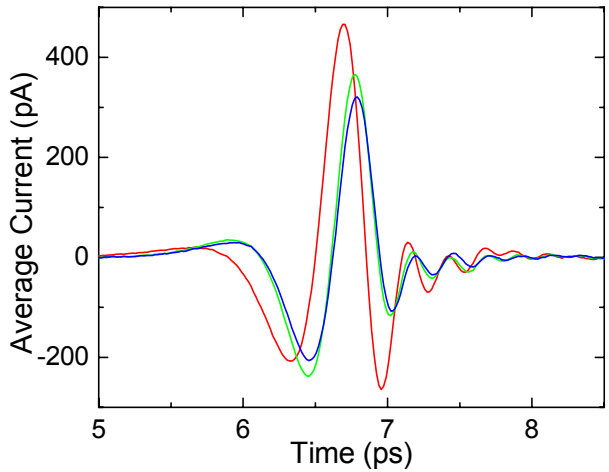
Parallel-Plate Waveguide

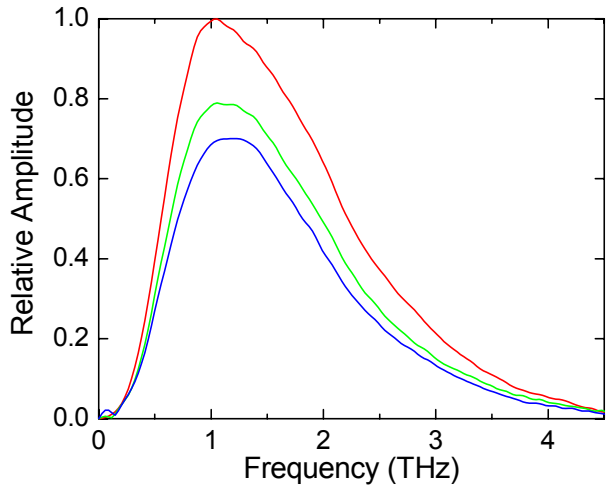
Attenuation

Dispersion



< 0.1 % change in velocity





Reference

12.6 mm

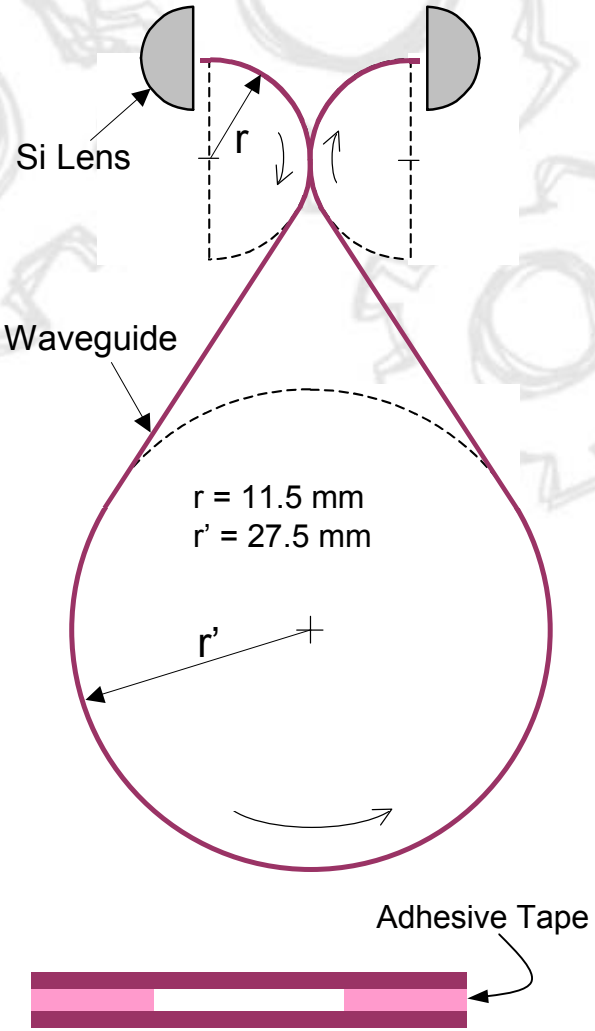
24.4 mm

R. Mendis, D. Grischkowsky
Opt. Lett. 26, 846 (2001)

OSU

University of Wollongong

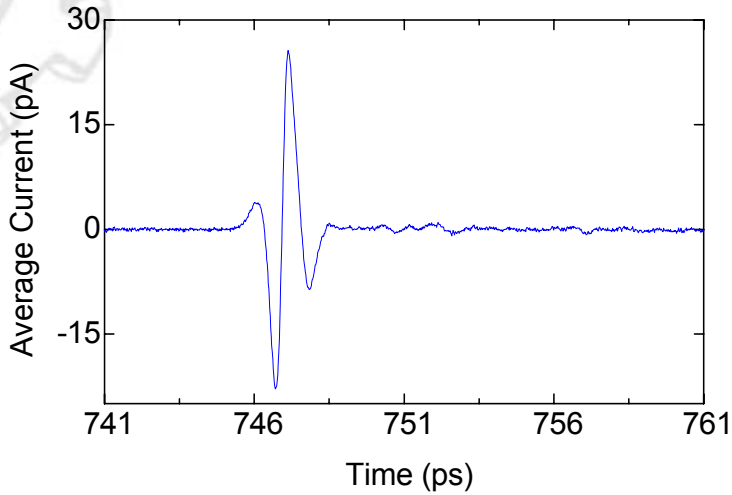
Parallel-Plate Waveguide

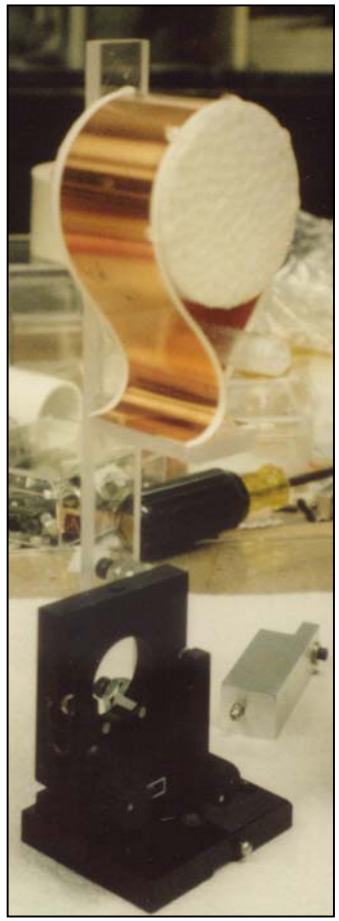


Copper Shims

90 μm separation

15 mm wide





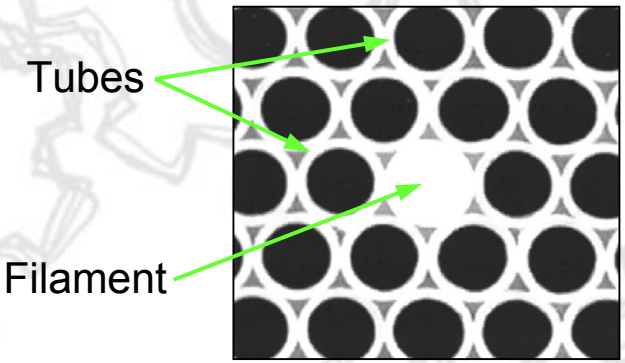
250 mm long

Flexible

R. Mendis, D. Grischkowsky

IEEE Microwave Wireless Comp. Lett. 11, 444 (2001)

Photonic Crystal Fiber



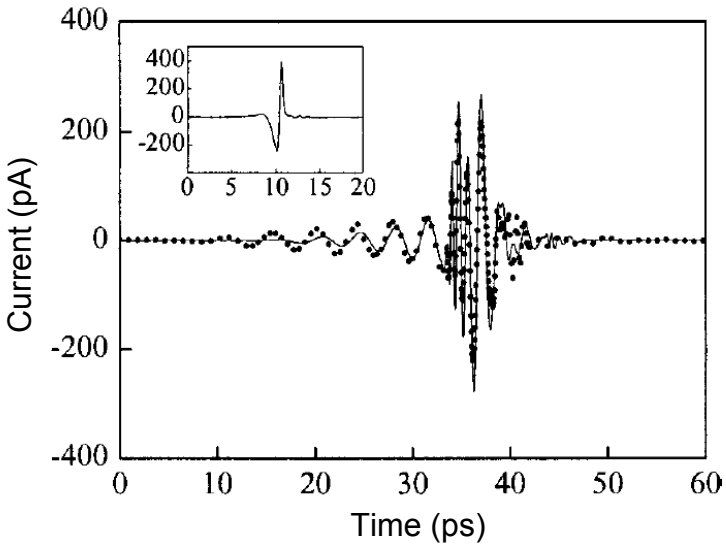
High-Index Core

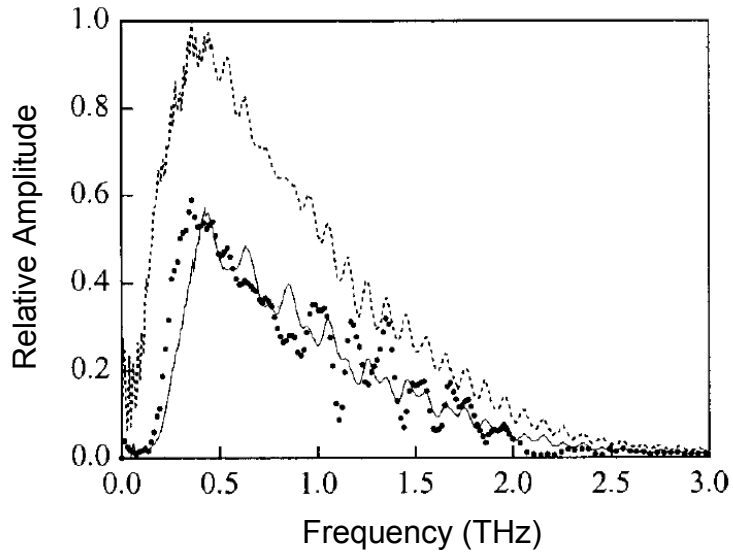
High Density Polythene

500 μm diameter Tubes

20 mm long

Field Attenuation < 0.25 cm^{-1}





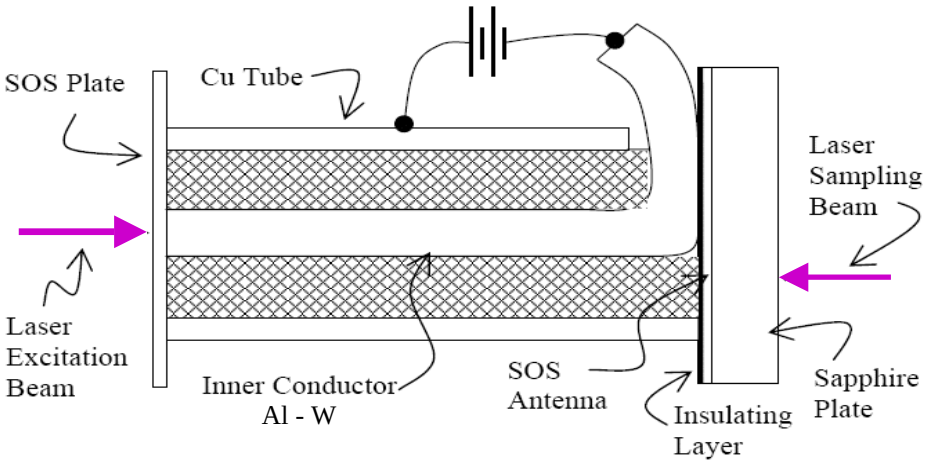
Positive Chirp

1ps ➞ 35 ps

Single-Mode

H. Han, H.Park, M. Cho, J. Kim
App. Phys. Lett. 80, 2634 (2002)

Coaxial Waveguide



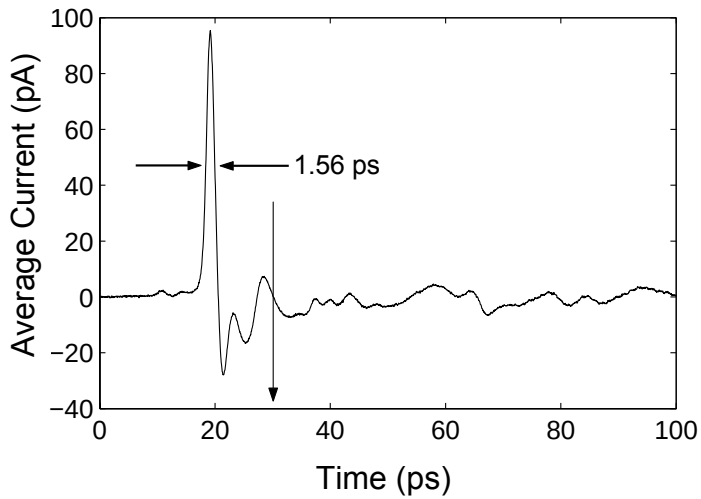
260 μm (inner) diameter Cu Tube

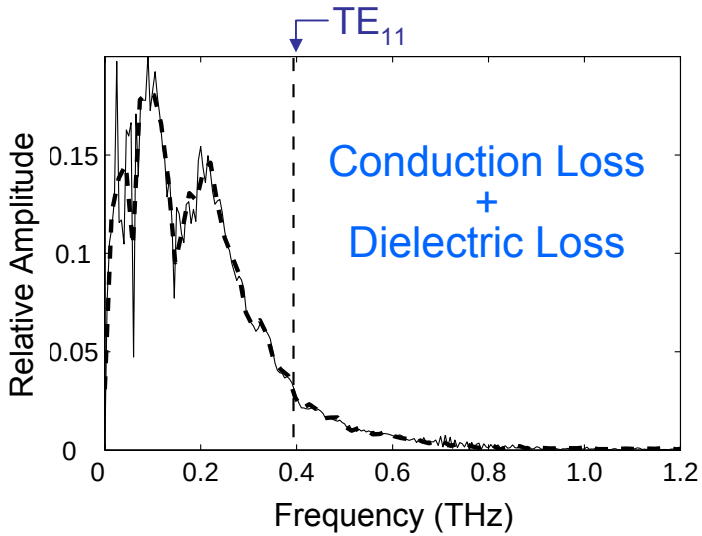
80 μm diameter Al-W Core

Teflon

105 mm long

Direct Generation & Detection





Undistorted Propagation

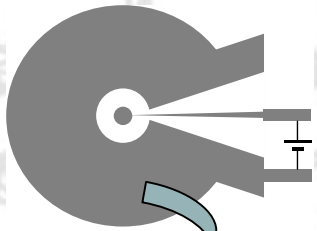
"Effectively"
Single-Mode (TEM)

T.-I. Jeon, D. Grischkowsky
App. Phys. Lett. 85, 6092 (2004)

OSU

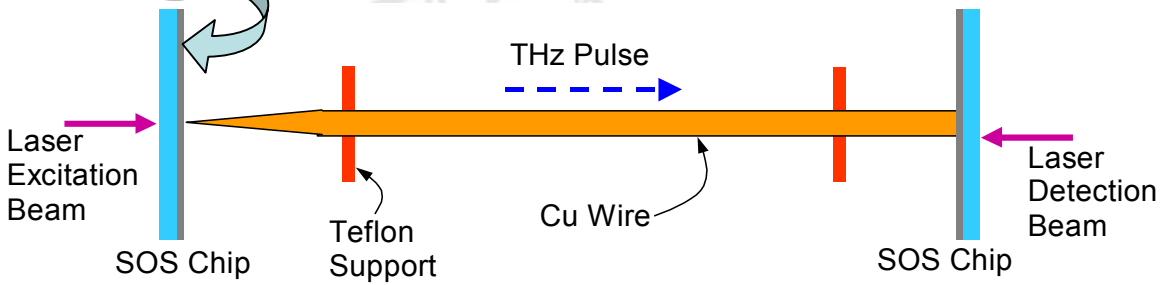
University of Wollongong

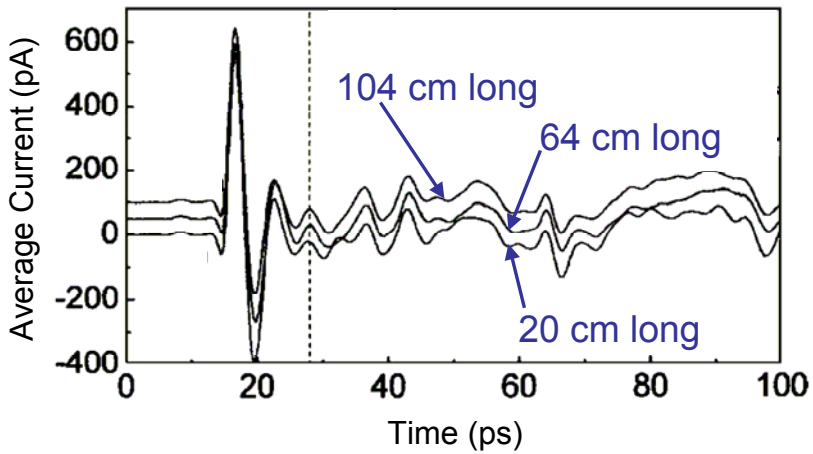
Metal Wire Waveguide

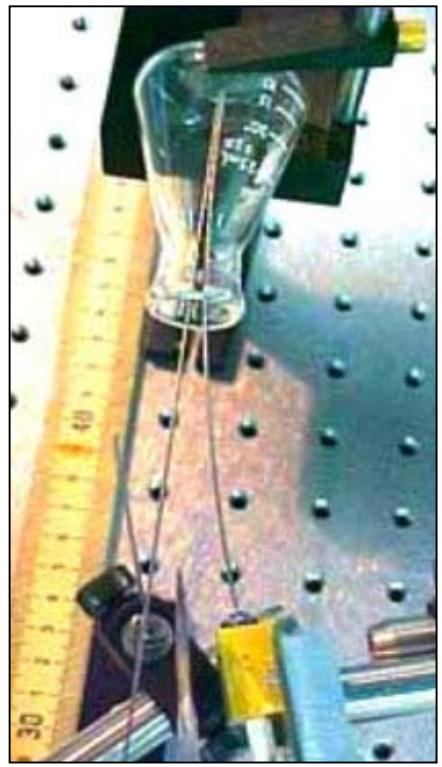


Copper

0.52 mm diameter







THz Endoscope

K. Wang, D. Mittleman
Nature 432, 376 (2004)

Undistorted Propagation

Single-Mode
(Sommerfeld)

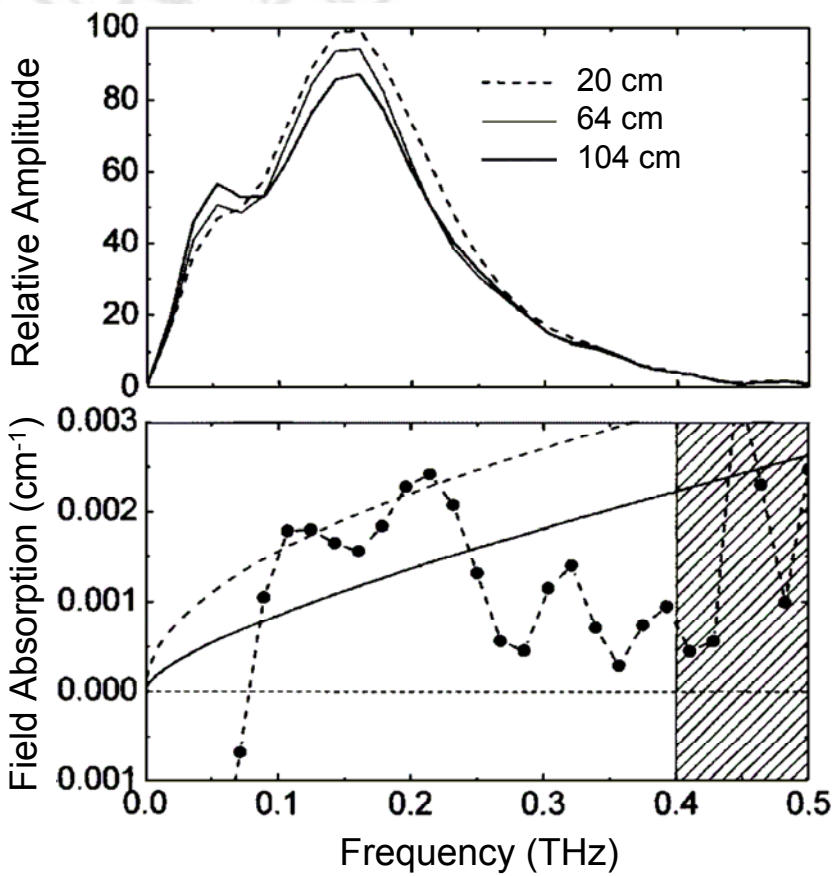
T.-I. Jeon, J. Zhang, D. Grischkowsky
App. Phys. Lett. 86, 161904 (2005)

Metal Wire Waveguide

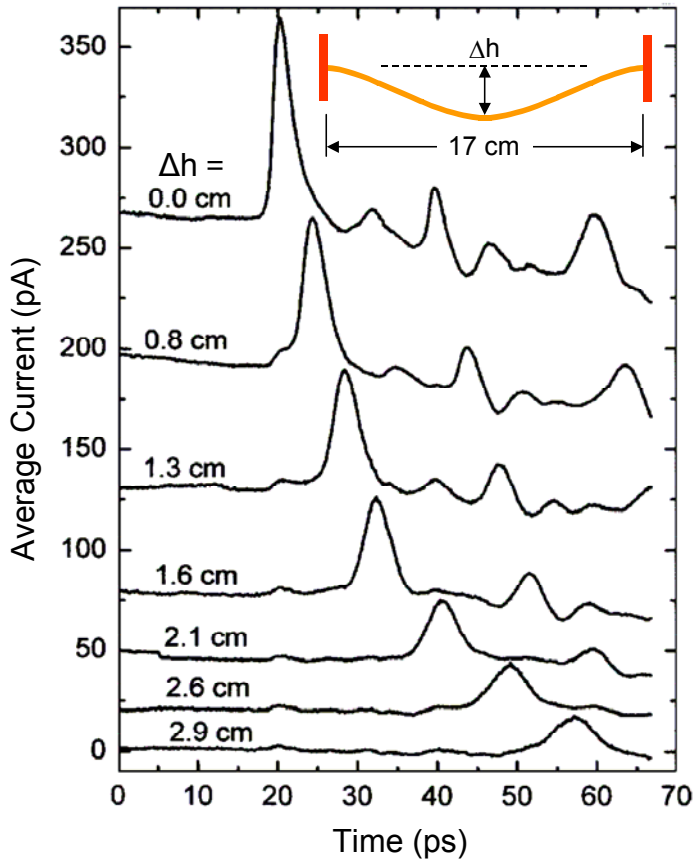
Copper

0.52 mm diameter

Attenuation



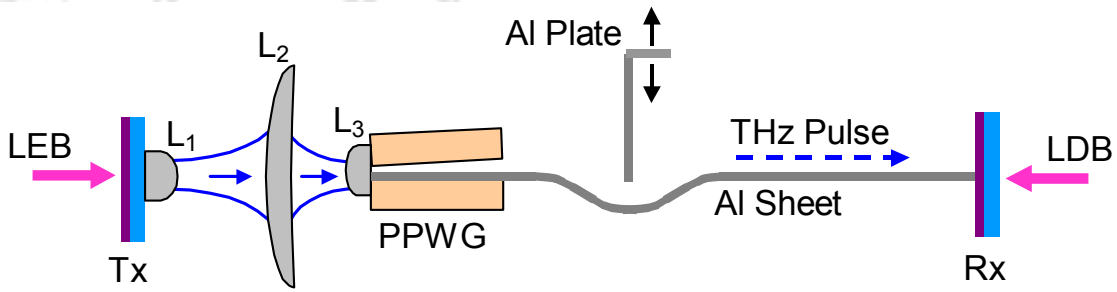
Dashed Line – Air-Filled Coaxial (TEM)



Bending Loss

T.-I. Jeon, J. Zhang, D. Grischkowsky
App. Phys. Lett. 86, 161904 (2005)

Metal Sheet Waveguide

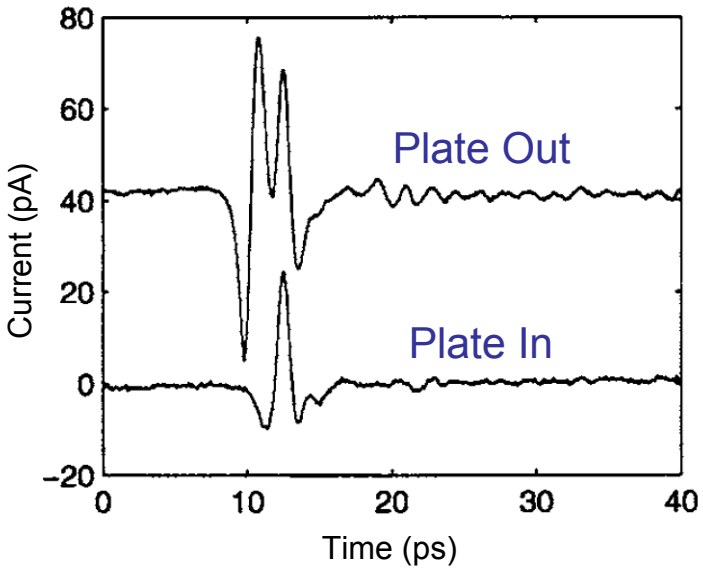


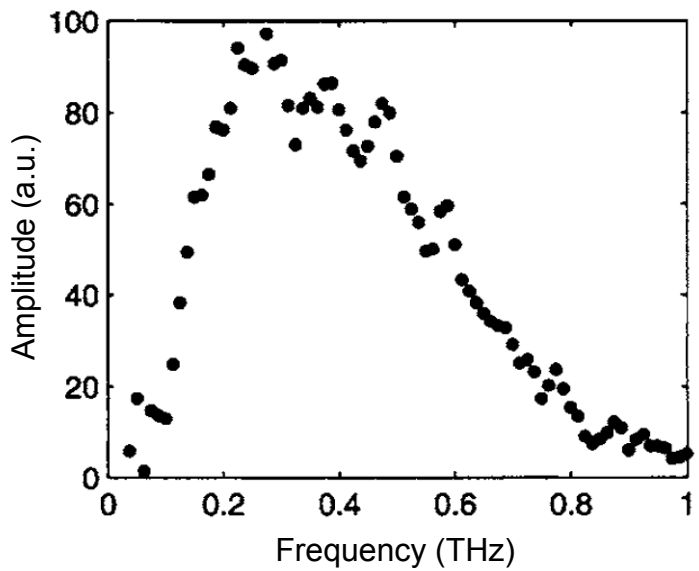
Aluminium

51 μm thick

10 cm wide

14 cm long





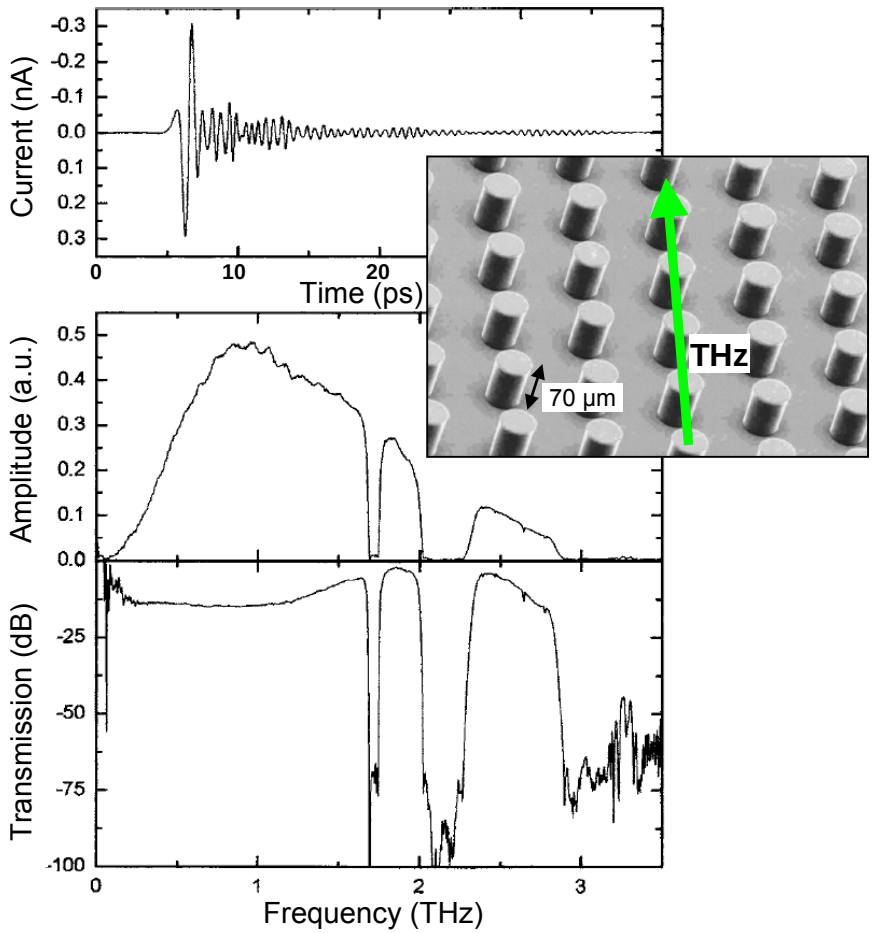
Undistorted Propagation

Single-Mode (Zenneck)

T.-I. Jeon, D. Grischkowsky
App. Phys. Lett. 88, 061113 (2006)

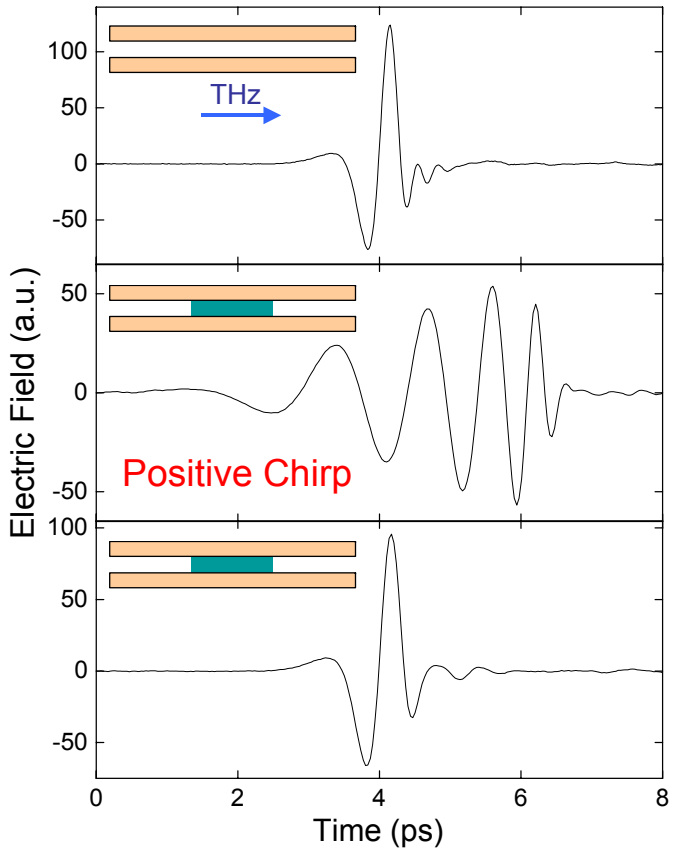
Parallel-Plate Variations

Parallel-Plate Photonic Waveguide



A. Bingham, Y. Zhao, D. Grischkowsky
App. Phys. Lett. 87, 051101 (2005)

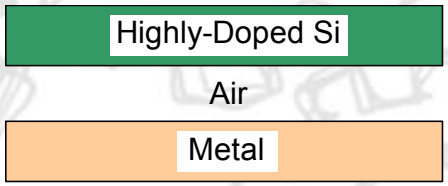
Dielectric-Filled Parallel-Plate Waveguide



R. Mendis
Opt. Lett. 31, 2643 (2006)

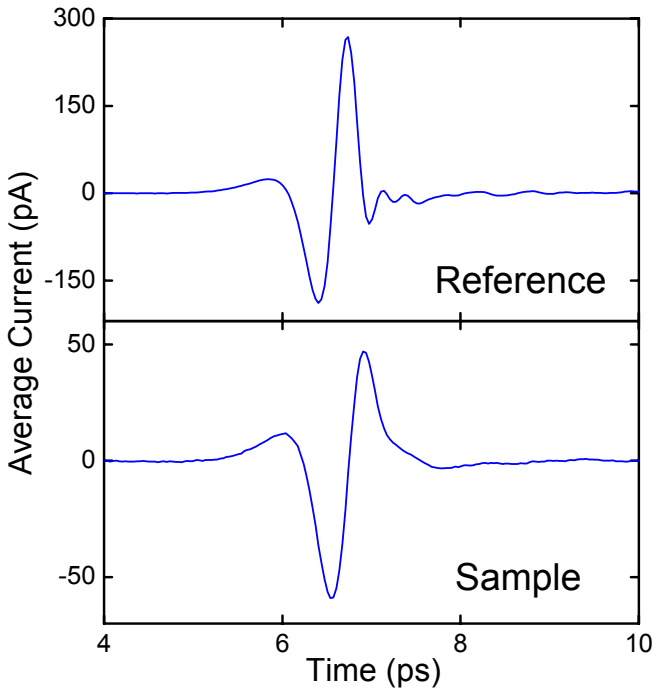
Guided-Wave THz-TDS

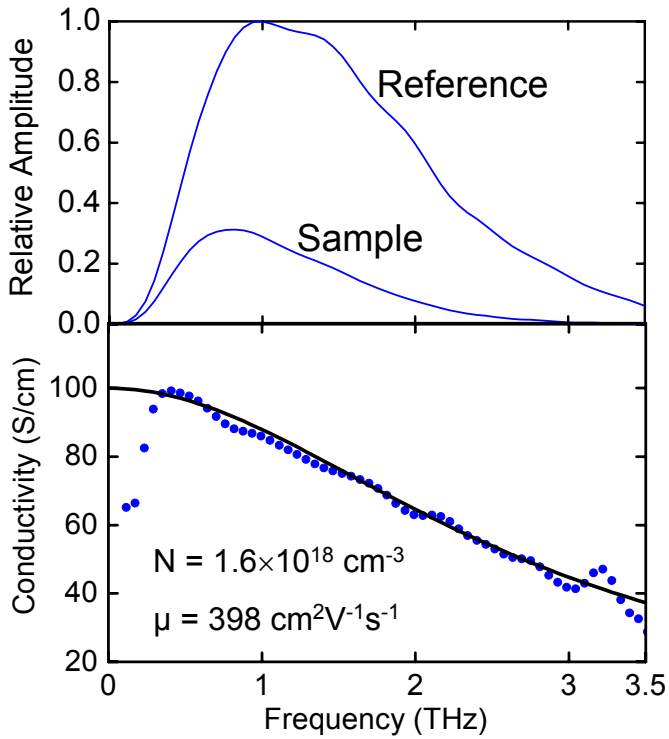
Parallel-Plate Waveguide



5.75 mm long
130 μm separation

- Highly-Doped Semiconductors
- Conducting Polymers
- Superconductors
- Metals





R. Mendis
Electron. Lett. 42, 26 (2006)

Collaborators

Oklahoma State University, USA

Dan Grischkowsky

Roger McGowan

Alan Cheville

Tae-In Jeon

Guilhem Gallot

Weili Zhang

John O'Hara

Jianquang Zhang

Steve Jamison

Abul Azad

University of Wollongong, Australia

Chao Zhang

Roger Lewis

Rodney Vickers

Michael Smith