Office of Nonproliferation and
Verification Research and Development

University and Industry Technical Interchange (UITI2010) Review Meeting

Single Mode Hollow Core Waveguides for Mid-Wave and Long-Wave Infrared Lasers

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Jason Kriesel
Opto-Knowledge Systems, Inc. (OKSI)

Single Mode Waveguides for IR Lasers

Lead Institution:
Opto-Knowledge Systems, Inc. (OKSI)
Torrance CA / www.oksi.com
Jason Kriesel (jason@oksi.com) – PI
Nahum Gat

Collaborating Institution:
Rutgers University
Specialty Fiber Optics Laboratory
Piscataway NJ / irfibers.rutgers.edu
Prof. Jim Harrington (jaharrin@rutgers.edu)
Carlos Bledt

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Victoria Franques

Technical Support:
Pacific Northwest National Laboratory
Richland WA / pnl.gov
Norm Anheier
Tanya Myers
Bruce Bernacki

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Daylight Solutions
San Diego CA / daylightsolutions.com
Chris Armacost

Project Overview

Status: Phase II STTR started October 2010 (Phase I completed May 2010)

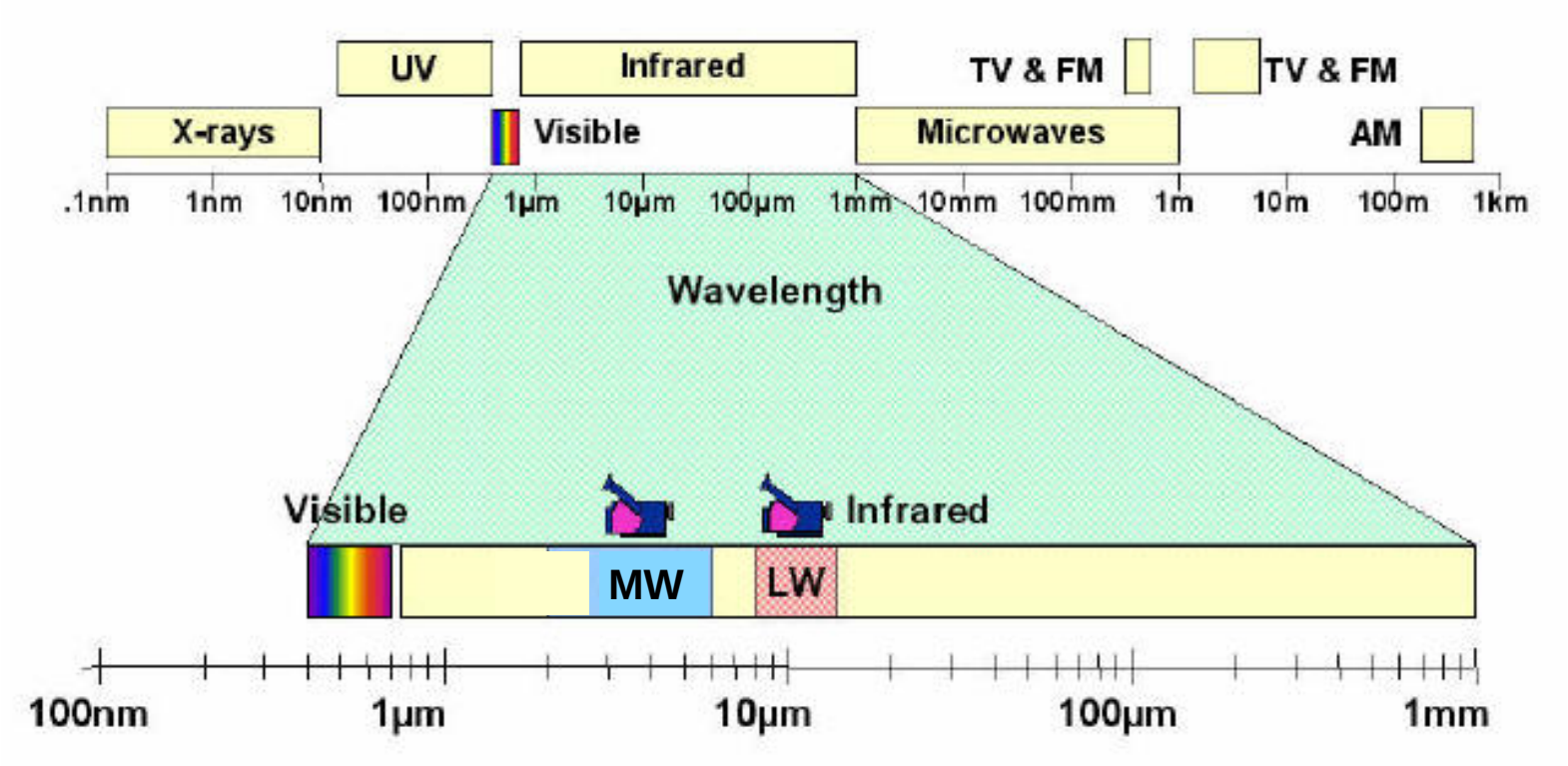
Goal: Develop single-mode fiber optics for Long Wave Infrared (LWIR), 7 to 14 µm, lasers

Motivation: Improve convenience, utility, and performance of LWIR spectroscopy, calibration, and quantum cascade laser (QCL) based systems

Problem: Solid-core fibers (e.g., chalcogenide) do not transmit effectively beyond 9 µm, are extremely brittle, and have end reflection issues

Solution: Hollow-core Glass Waveguides developed by Prof. Harrington at Rutgers

Infrared Wavelength Region



- Long-Wave Infrared (LWIR): 7 to 14 µm
- Mid-Wave Infrared (MWIR): 3 to 6 µm
- Mid-Infrared: 2 to 25 µm (5000 to 400 cm^{-1})

Infrared Spectroscopy

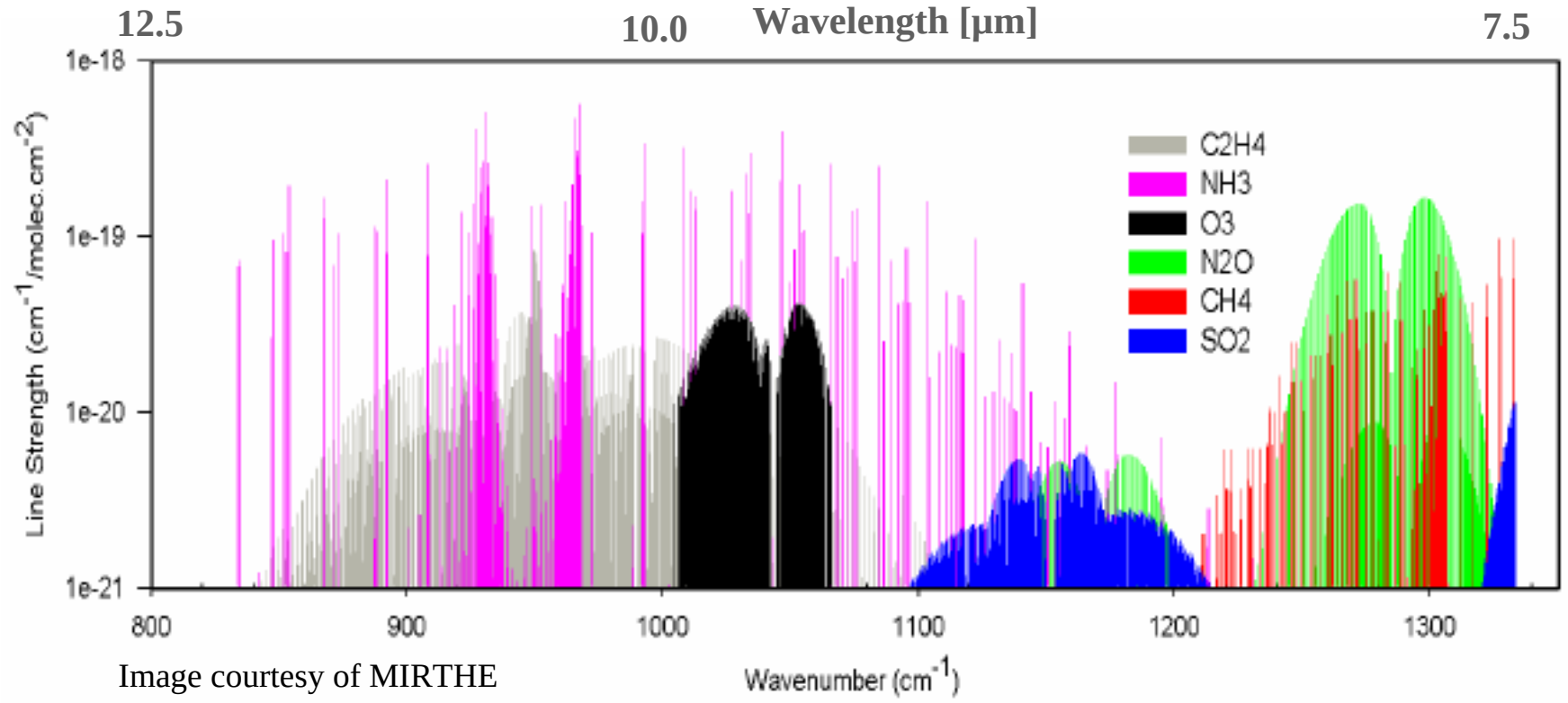


Image courtesy of MIRTHE

Molecular Finger Print

- Defense / security (e.g., WMD)
- Biomedical diagnostics
- Environmental monitoring
- Isotope ratio

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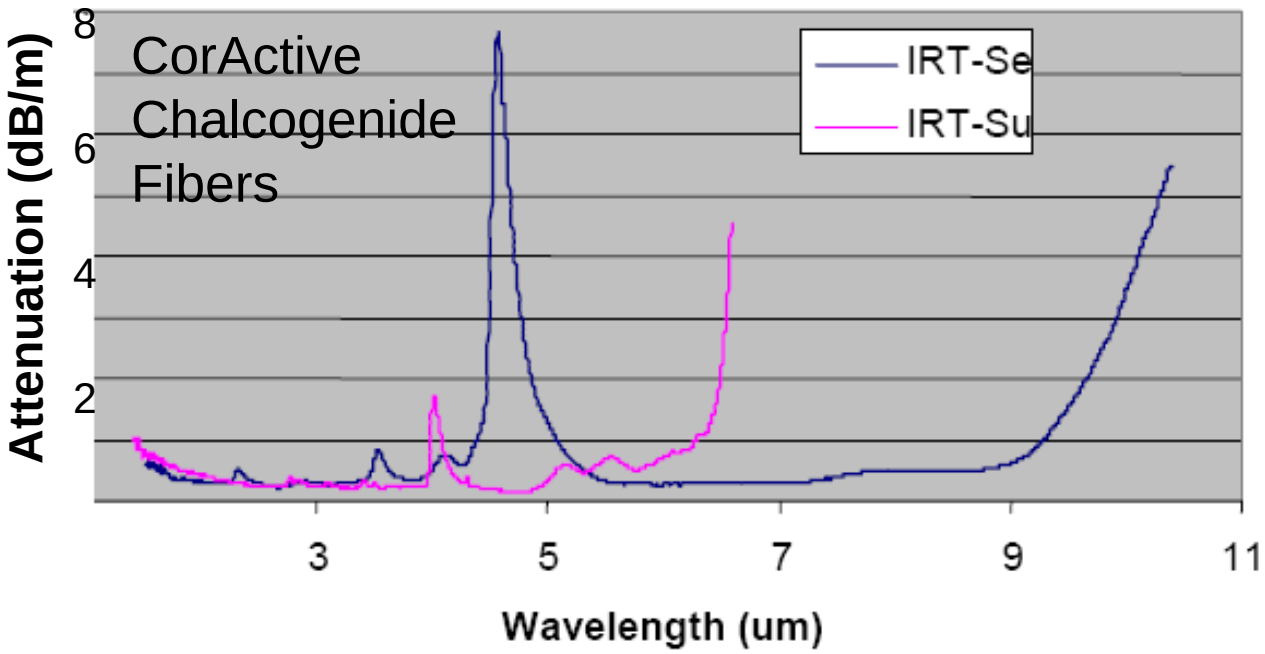
Solid Core IR Fibers



- Losses are too high in the LWIR range
- Expensive

- Extremely fragile and brittle
- Generally difficult to work with
- End reflections can cause laser feed back
- Cladding modes diminish beam quality

K. Krishnaswami, et.al. “Characterization of Single-mode Chalcogenide Optical Fiber for Mid-Infrared Applications”, Proc. of the SPIE, Volume 7325 (2009).

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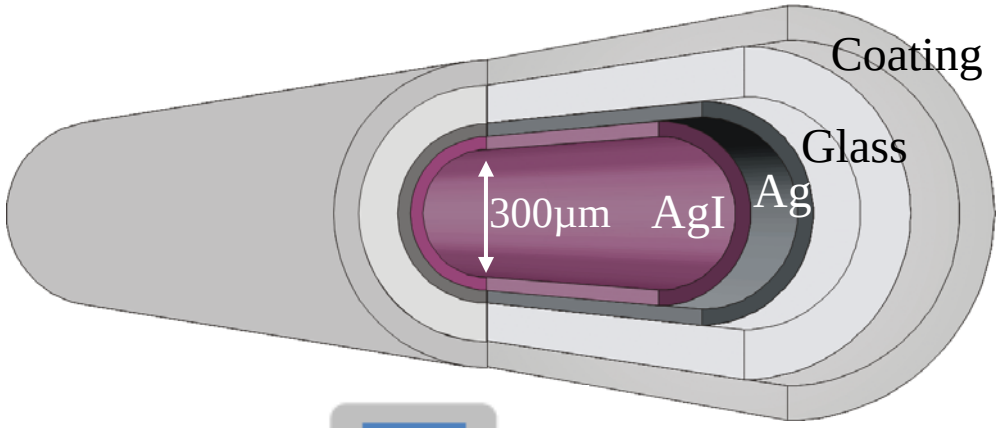
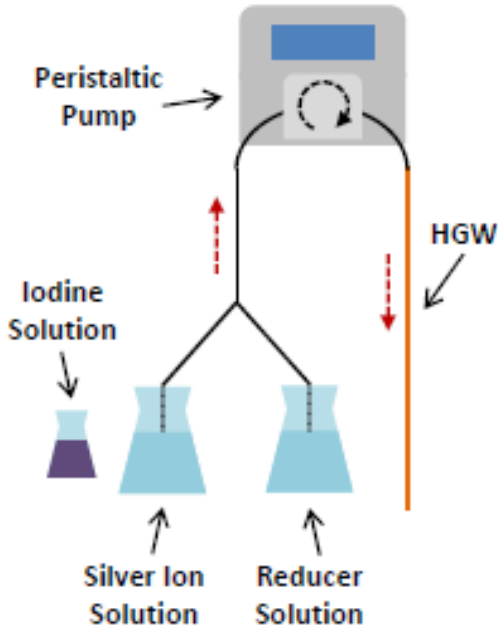
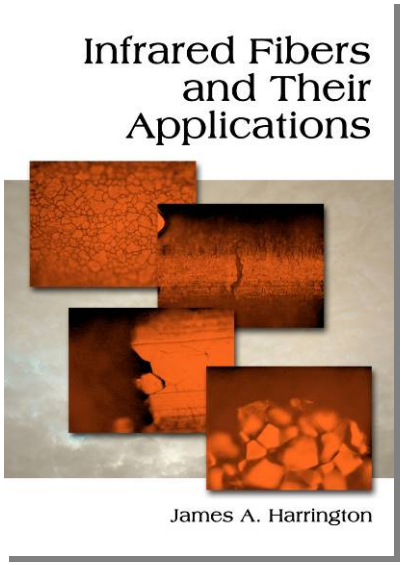
Hollow Core Glass Waveguides (HGW)







Hollow Core Glass Waveguides:

- Excellent Infrared transmission out to 20 µm
- Proven single mode delivery for bore size ~ 30λ
- No end reflections
- High damage threshold
- Very Robust
- 20+ years of experience at Rutgers

Bending loss is the primary concern

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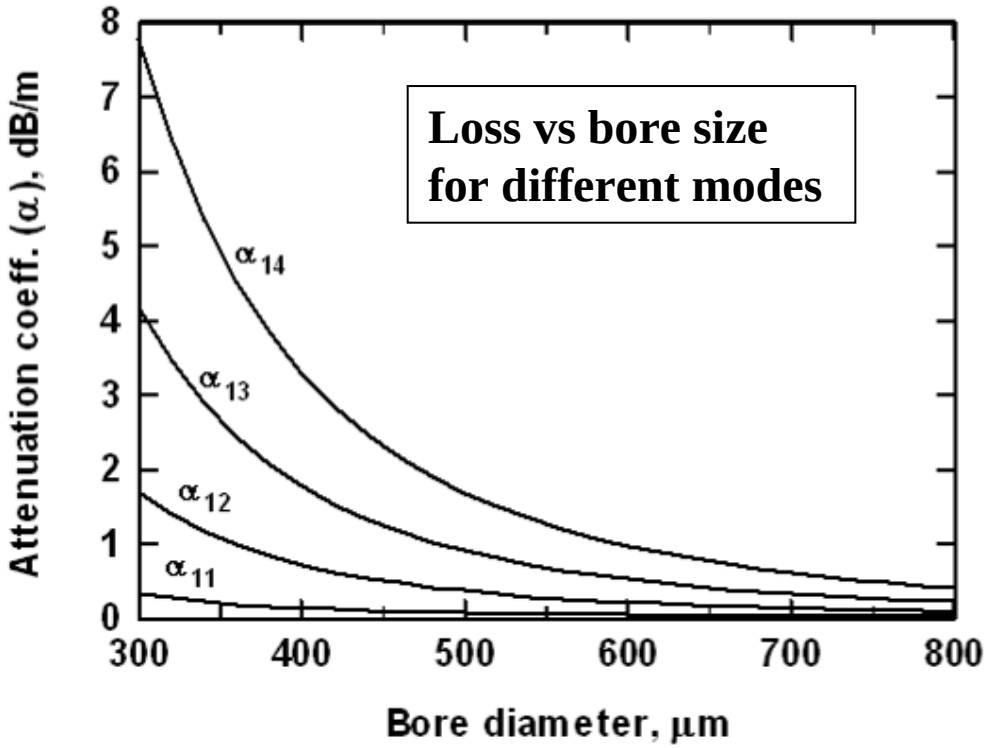
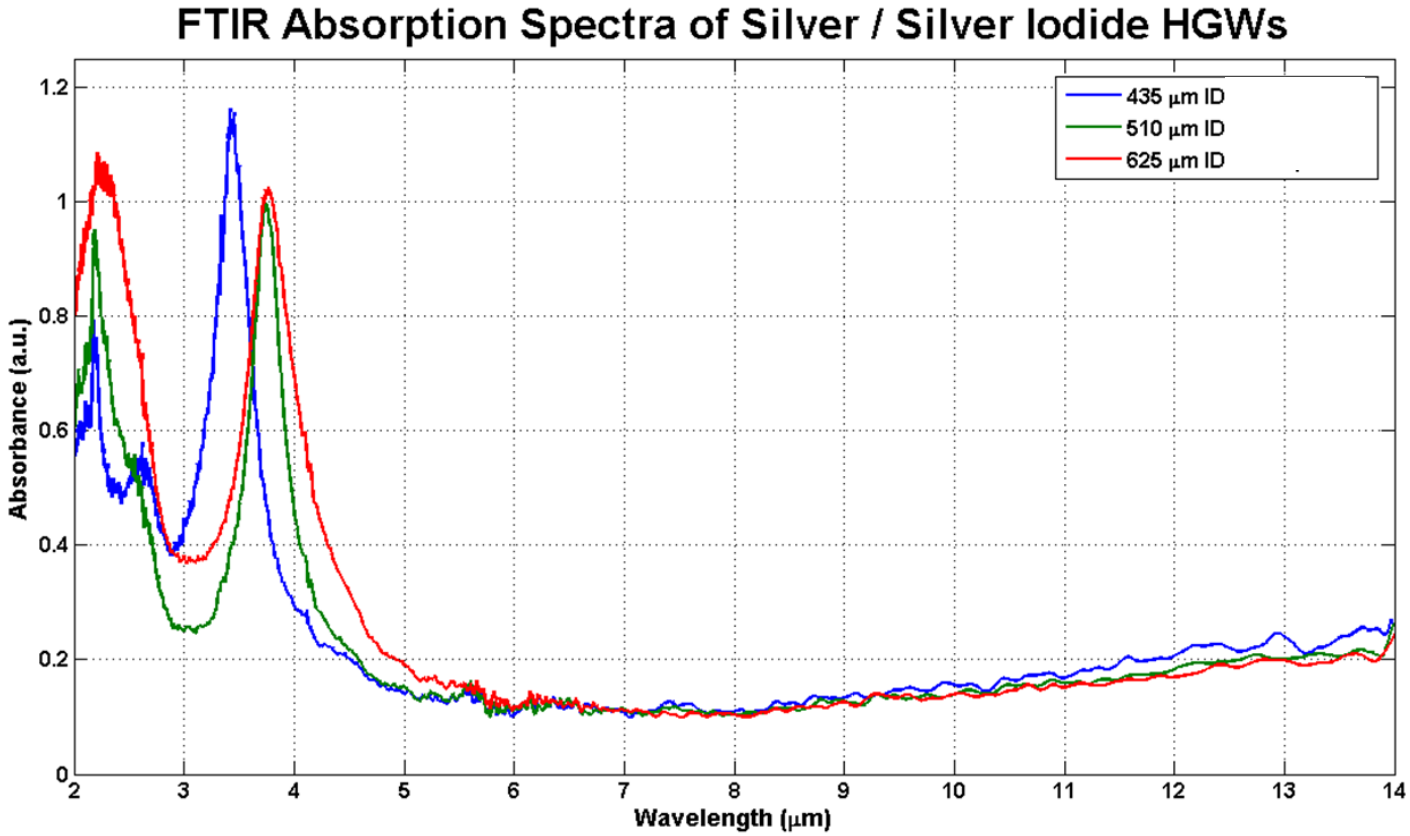
Losses for Hollow Glass Waveguide



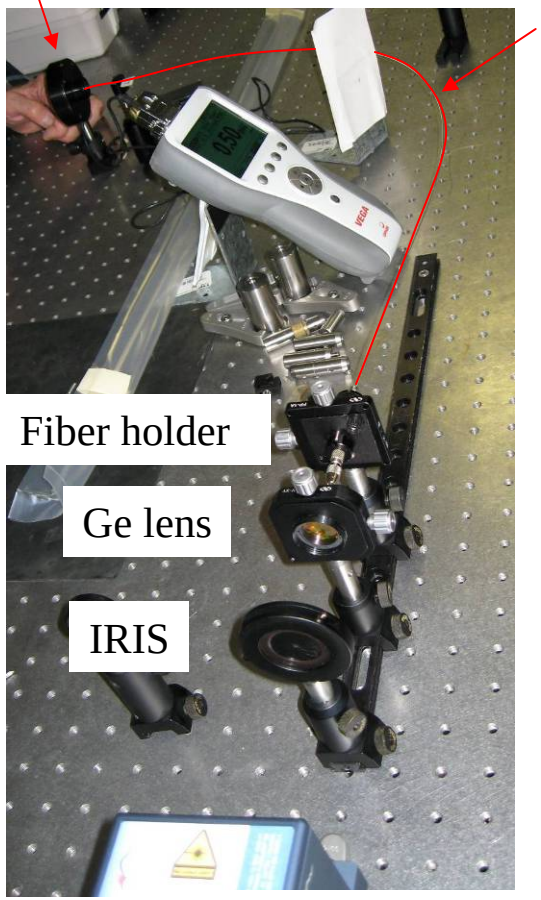
- Loss ~ 1/(Bore Size)^3 => greater loss for smaller waveguides
- Loss higher for higher order modes => mode filtering
- Bends couple energy into higher order modes => greater loss on bending

Project Results – Spectral Transmission

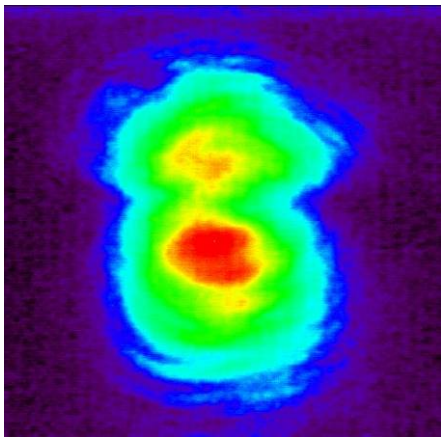


- Loss is relatively low even at longer wavelengths up to λ = 20 µm
- Coatings can also be tailored for shorter wavelengths including visible (e.g., 0.4 to 0.7 µm)

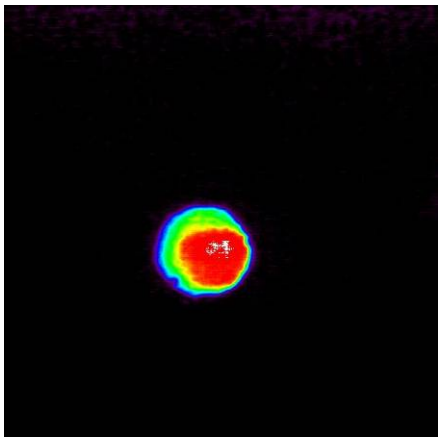
Project Results – QCL Measurements



Raw QCL Beam



Filtered QCL Beam



Bore Size	300 um (single mode)		500 um (multi-mode)	
QCL Beam	Raw	Filtered	Raw	Filtered
Straight loss	2.5 dB/m	1.5 dB/m	1.9 dB/m	0.4 dB/m
Bending loss	0.1 dB	0.1 dB	0.1 dB	0.3 dB

QC Laser: 9 to 10 µm tunable
from Daylight Solutions

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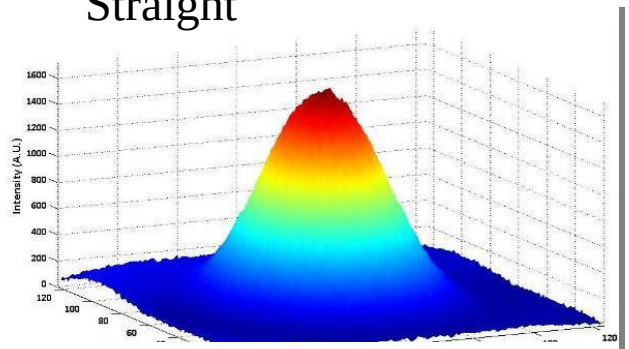
Project Results – Single Mode Output

Improve Output Mode Performance by Using Modified Structure

Standard Multi-Mode Waveguide

Straight



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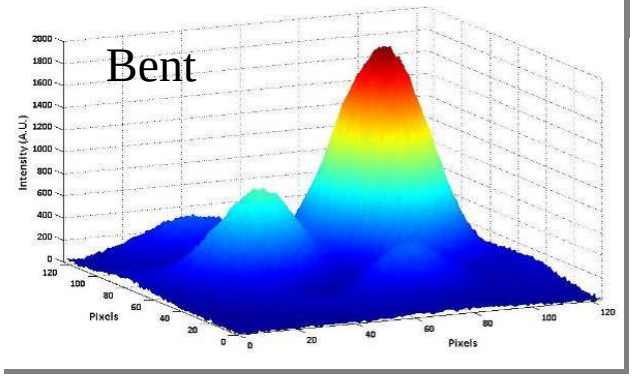
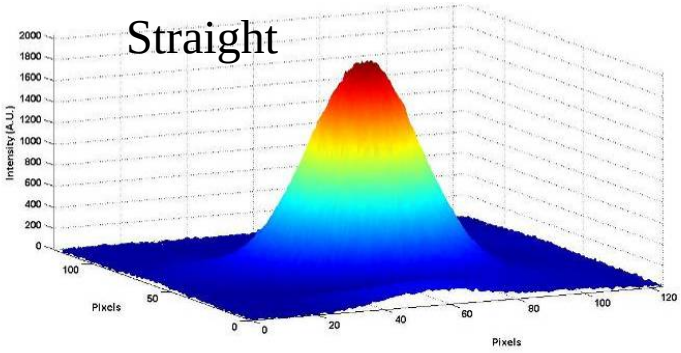


Single-Mode Waveguide

Straight



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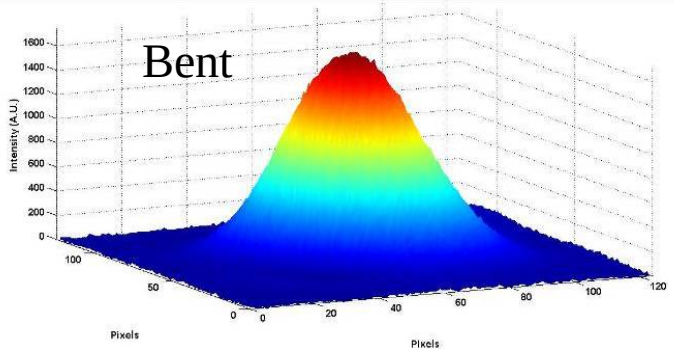
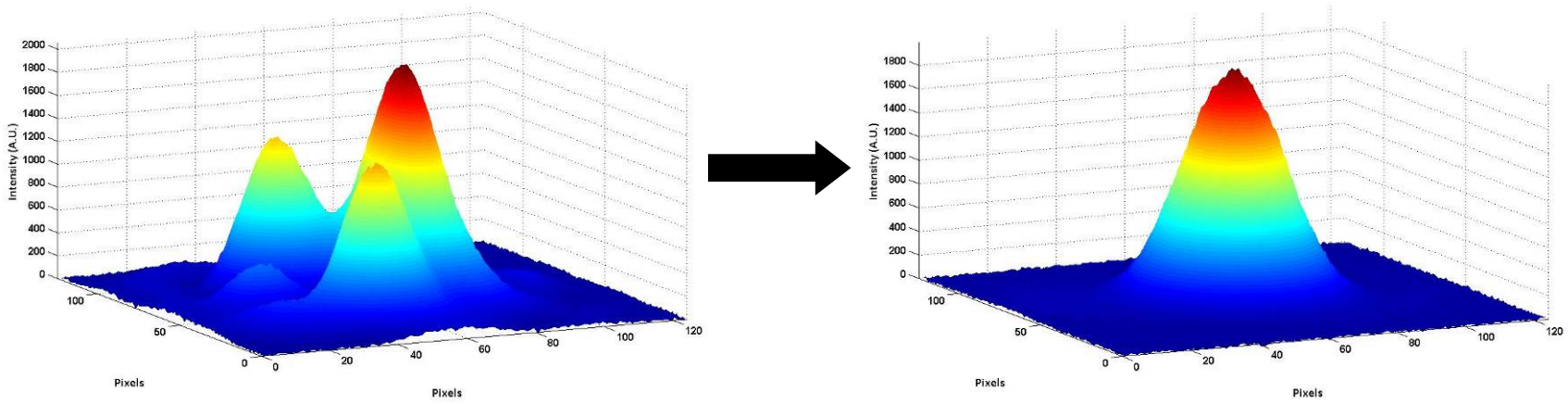


Additional independent studies by PNNL (Bernaki, et.al.) confirm single mode performance.

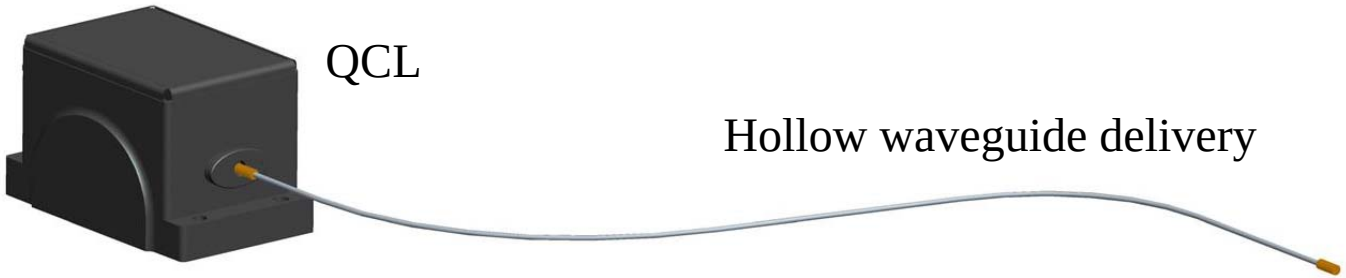
Project Results – Mode Filtering



- Higher order modes damped by waveguide => Mode Filtering
- Waveguide can be used to “clean-up” QCL beams

On Going R&D

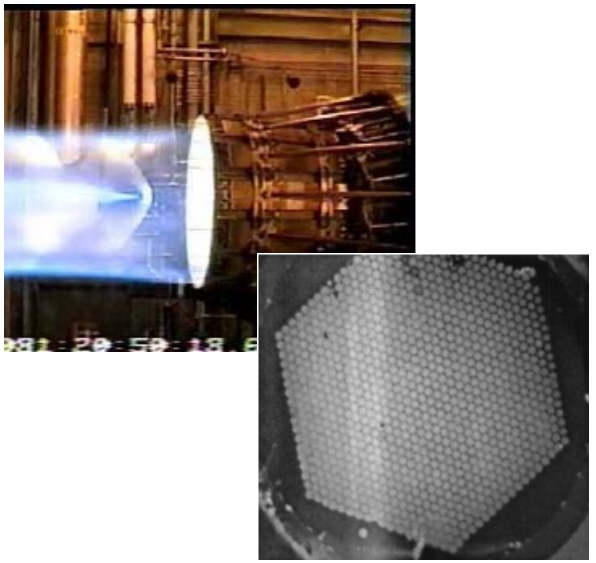
- Reduce loss of standard Ag/AgI coating
- Develop advanced multi-layer coatings with even lower losses
- Characterize loss / mode quality with QC Laser
- Fully transfer technology from Rutgers to OKSI
- Develop complete solutions specific for PNNL
- Develop complete fiber delivery solutions for commercial QCL's



Related Projects / Applications

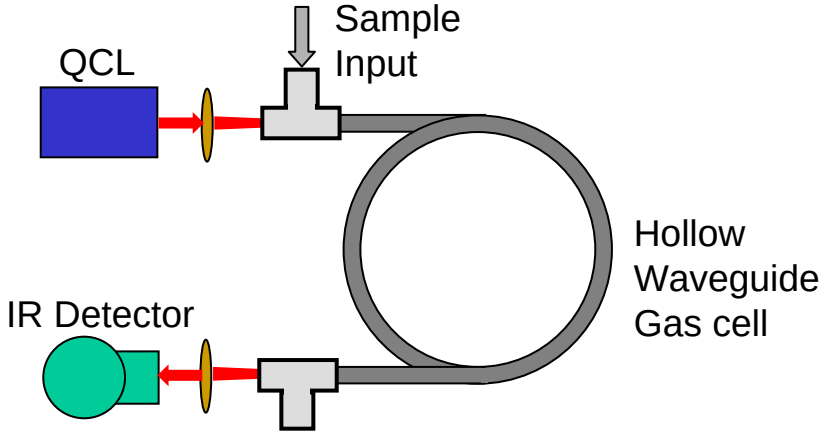
Current hollow waveguide projects at OKSI:

- Beam delivery for high-energy short-pulsed laser combustion/propulsion diagnostics (Air Force – Phase II)
- IR waveguide imaging bundles (Air Force – Phase I)



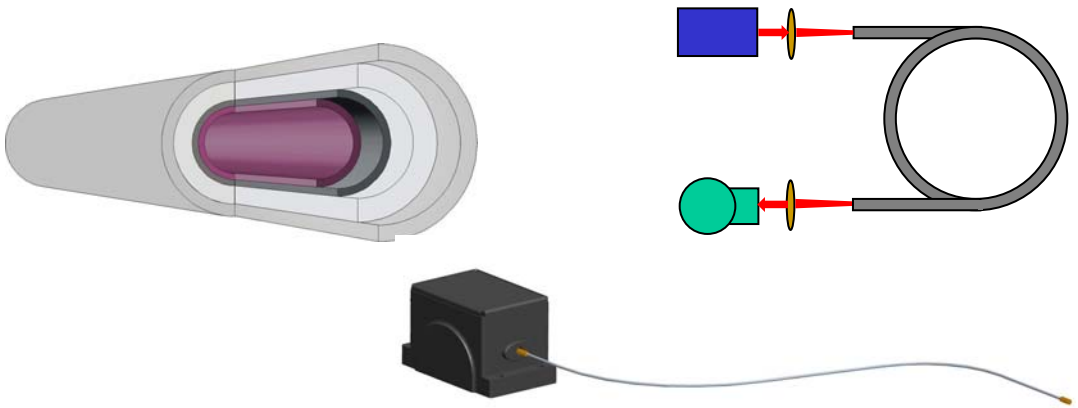
Other applications being pursued:

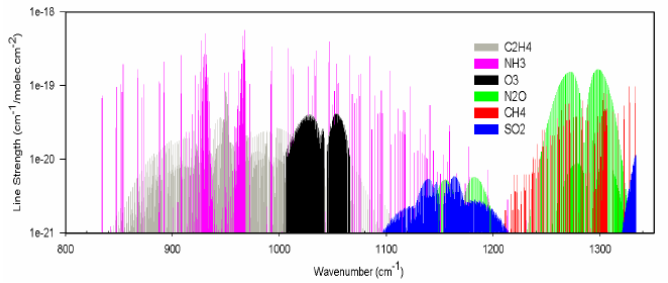
- Hollow waveguides gas sensors for high sensitivity IR spectroscopy
- Laser delivery for IR counter measures
- CO_2 laser delivery for medical & industrial applications



Summary

- LWIR (7 to 14 µm) spectroscopy and laser systems are important for non-proliferation and counter-terrorism applications
- LWIR laser systems can benefit greatly from fiber delivery
- Solid fibers have significant drawbacks particularly at longer wavelengths
- Hollow glass waveguides are a proven low-loss, single-mode delivery solution
- Development and testing is focused on reducing loss and producing complete solutions for QCL based systems of specific interest to PNNL / NNSA





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