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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Single Mode Waveguides for IR Lasers

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Victoria Franques

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

**Acknowledgements:**
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
- 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

Molecular Finger Print

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

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
Losses for Hollow Glass Waveguide

- Loss $\sim 1/(\text{Bore Size})^3$ => greater loss for smaller waveguides
- Loss higher for higher order modes => mode filtering
- Bends couple energy into higher order modes => greater loss on bending
Loss is relatively low even at longer wavelengths up to $\lambda = 20 \, \mu m$

Coatings can also be tailored for shorter wavelengths including visible (e.g., 0.4 to 0.7 $\mu m$)
Project Results – QCL Measurements

Power Meter Head

HGW
90° Bend
R = 0.2 m

Fiber holder

Ge lens

IRIS

QC Laser: 9 to 10 µm tunable
from Daylight Solutions

<table>
<thead>
<tr>
<th>Bore Size</th>
<th>300 um (single mode)</th>
<th>500 um (multi-mode)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QCL Beam</td>
<td>Raw</td>
<td>Filtered</td>
</tr>
<tr>
<td>Straight loss</td>
<td>2.5 dB/m</td>
<td>1.5 dB/m</td>
</tr>
<tr>
<td>Bending loss</td>
<td>0.1 dB</td>
<td>0.1 dB</td>
</tr>
</tbody>
</table>
Project Results – Single Mode Output

Improve Output Mode Performance by Using Modified Structure

**Standard Multi-Mode Waveguide**

- Straight
- Bent

**Single-Mode Waveguide**

- Straight
- Bent

Additional independent studies by PNNL (Bernaki, et.al.) confirm single mode performance.
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
- CO₂ 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
Single Mode Waveguides for IR Lasers

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