
Gas Mapping LiDAR (Enabled by SCOWA* Technology) R&D 100 Staff Seminar

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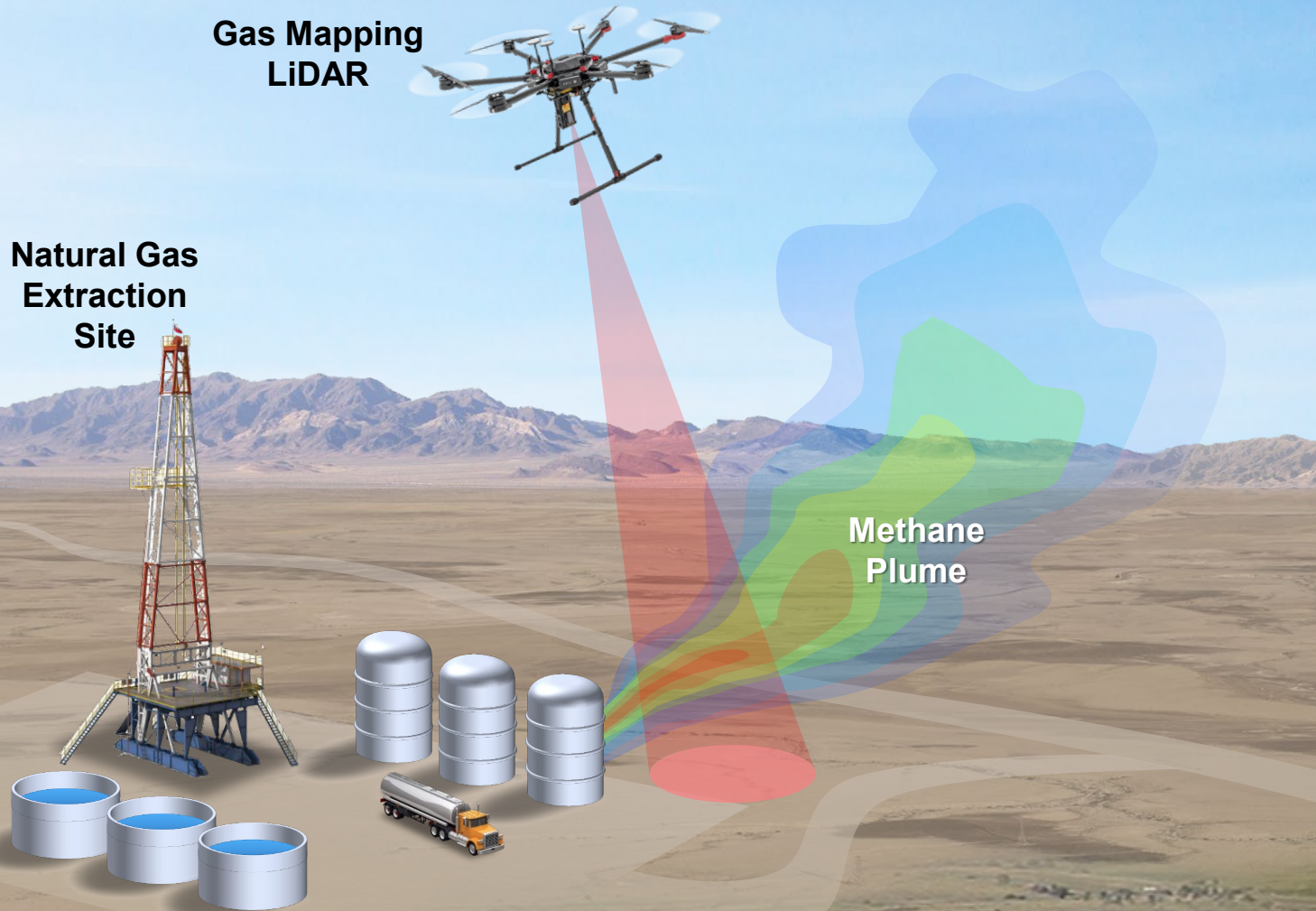
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***Slab-Coupled Optical Waveguide Amplifier**

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Detecting and Quantifying Methane Emissions

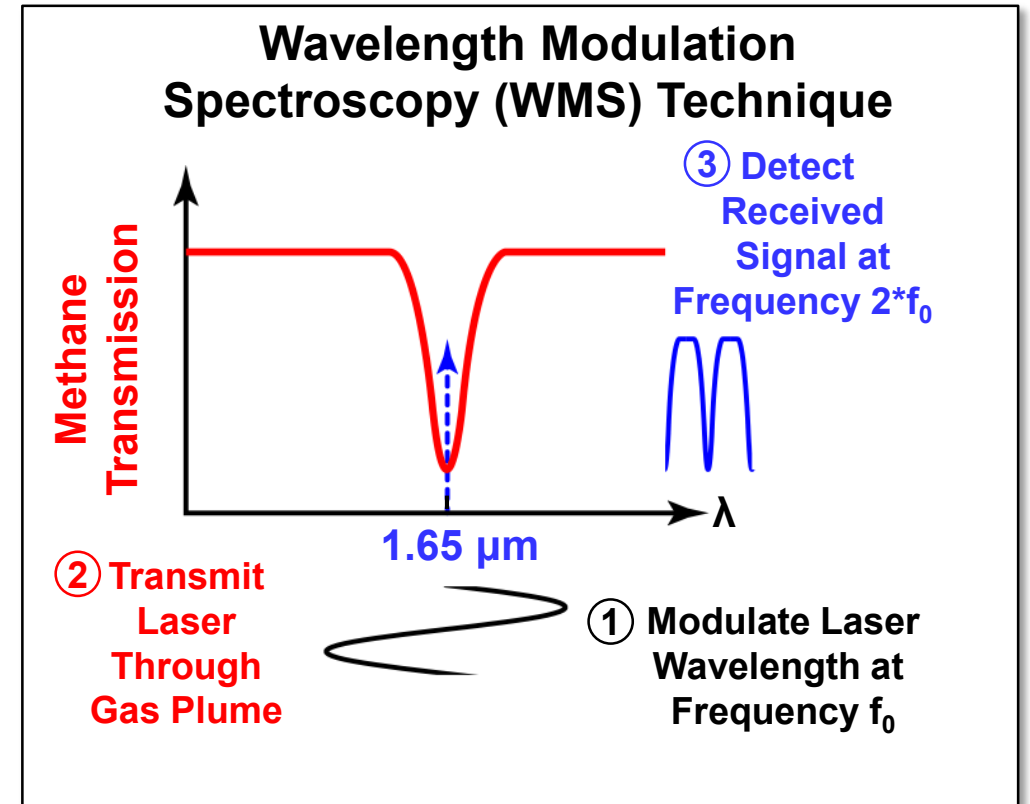
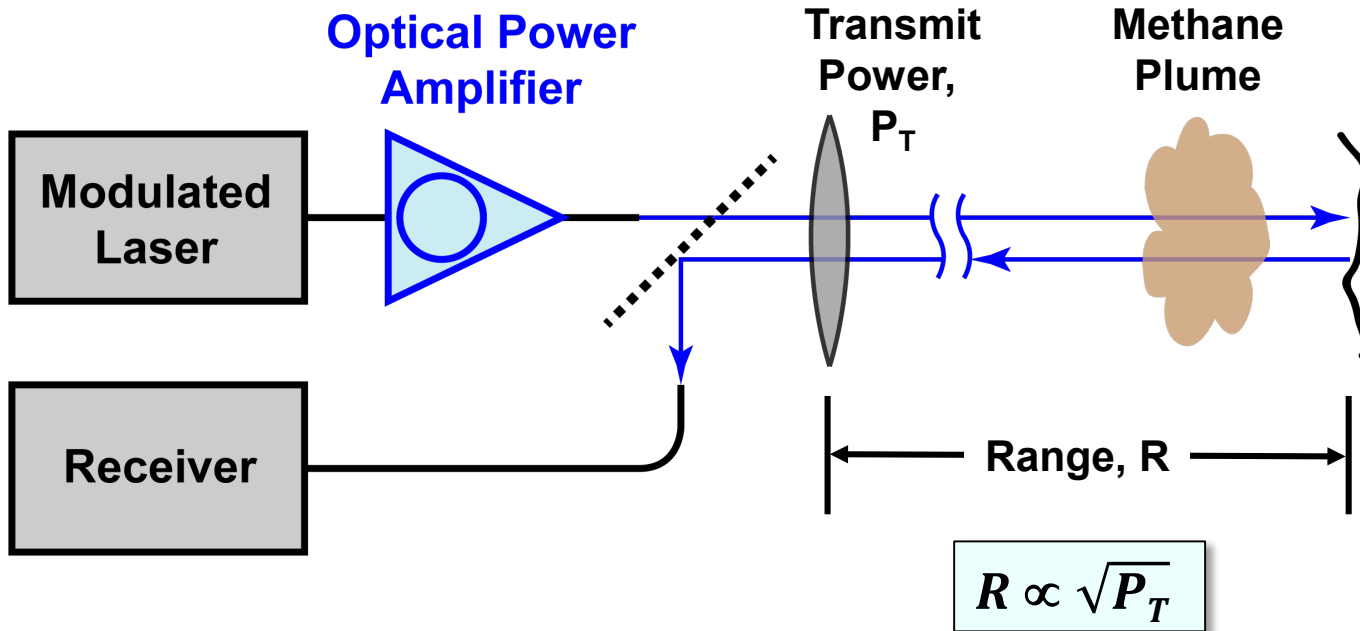


- Methane (CH_4) is estimated to have 25X-85X the global warming potential (GWP) of carbon dioxide (CO_2)
- A recent study* estimates that the U.S. oil and natural gas supply chain emits ~13 million metric tons of CH_4 per year
 - 2.3% of gross U.S. gas production
 - Value of lost CH_4 ~ \$5B/year
 - 5-14% of the total U.S. greenhouse gas emission (CO_2 -equivalent)
- ARPA-E's Methane Observation Networks with Innovative Technology to Obtain Reductions (MONITOR) program initiated in 2014 to develop remote, low-cost systems for locating and quantifying CH_4 emissions

*R. A. Alvarez *et al.*, *Science*, 2018



Gas Mapping LiDAR System Diagram

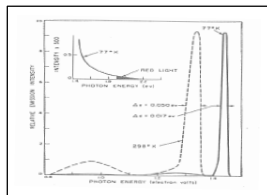


At start of collaboration, range of Bridger GML limited to ~150-300 ft by maximum output power (~20 mW) of optical amplifiers capable of operating at 1.65- μm wavelength

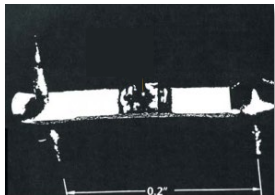


Highlights of Semiconductor Optical Emitter R&D at Lincoln Laboratory

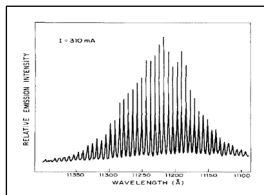
Efficient LEDs (1962)



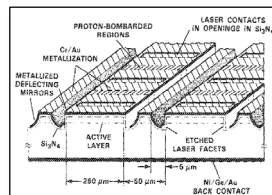
GaAs Diode Laser (1962)



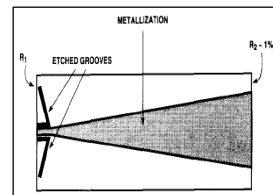
InGaAsP CW Laser (1976)



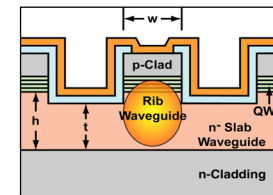
2D Laser Arrays (1987)



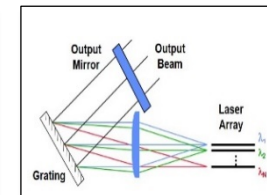
Tapered Laser / Amplifier (1991)



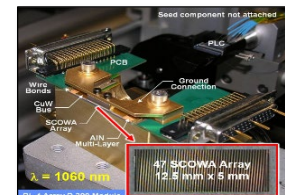
SCOW Laser (1999)



Wavelength Beam-Combining (1999)



Coherent Beam-Combining (2012)



1960

1990

2020

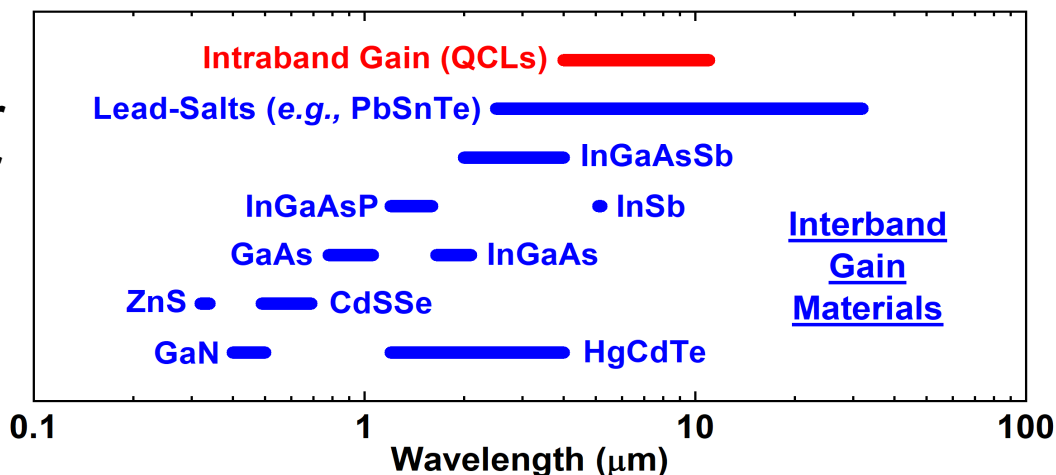
Spin-Off Companies

Laser Analytics (1974)

Lasertron (1980)

TeraDiode (2009)

Semiconductor Optical Emitter Materials Developed at MIT LL



- SCOW Amplifier (2003)
- SCOW Mode-Locked Laser (2005)
- SCOW Wavelength Beam-Combining (2005)
- SCOW External-Cavity Laser (2009)
- SCOW Coherent Beam-Combining (2012)
- SCOWA Gas Mapping LiDAR Demo (2017)

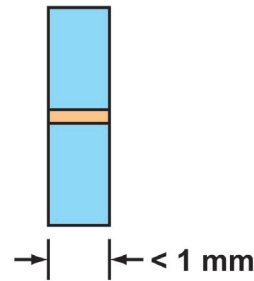
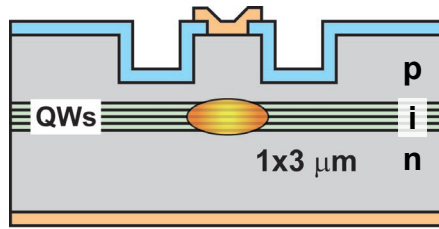


Comparison of Semiconductor Waveguide Optical Gain Media

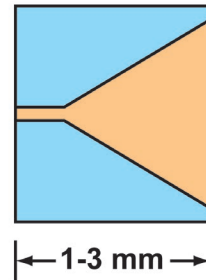
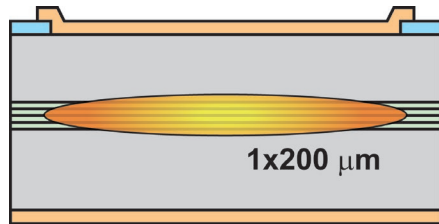
Output Facet Cross-Section

Top View

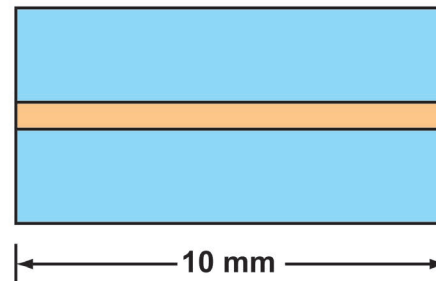
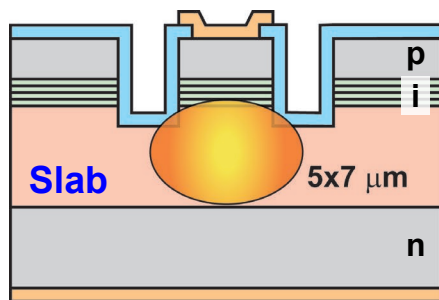
Rib Waveguide Amplifier



Tapered Amplifier



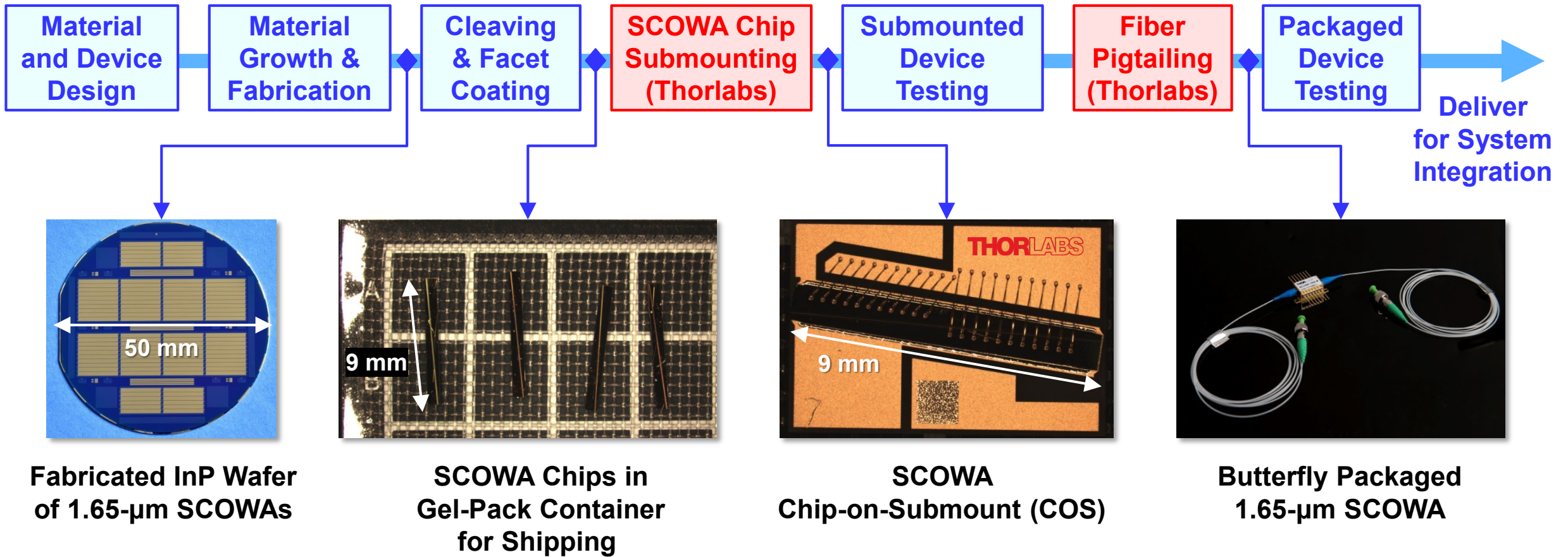
Slab-Coupled Optical Waveguide Amplifier (SCOWA)



High Power	Heat Removal	Large Mode	Stable Mode	Low Loss
< 0.1 W				
> 1 W				
> 1 W				



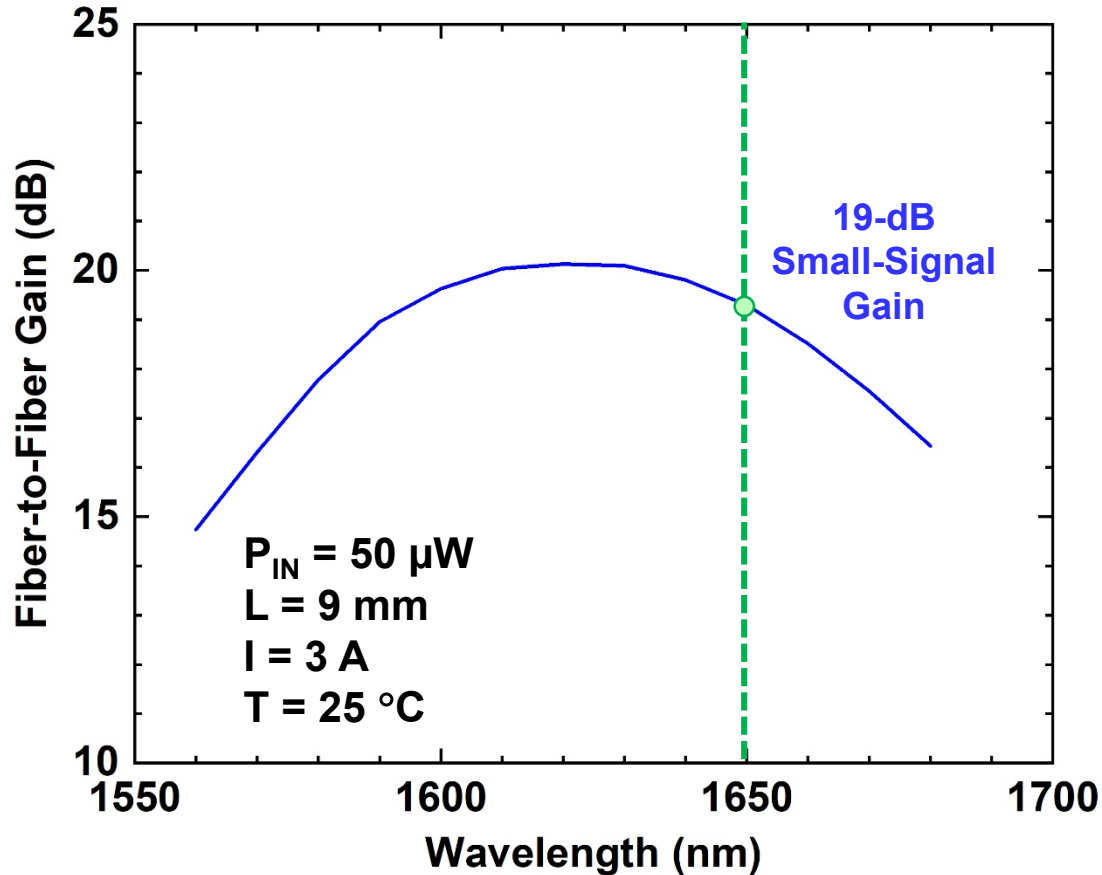
1.65- μm SCOWA Development



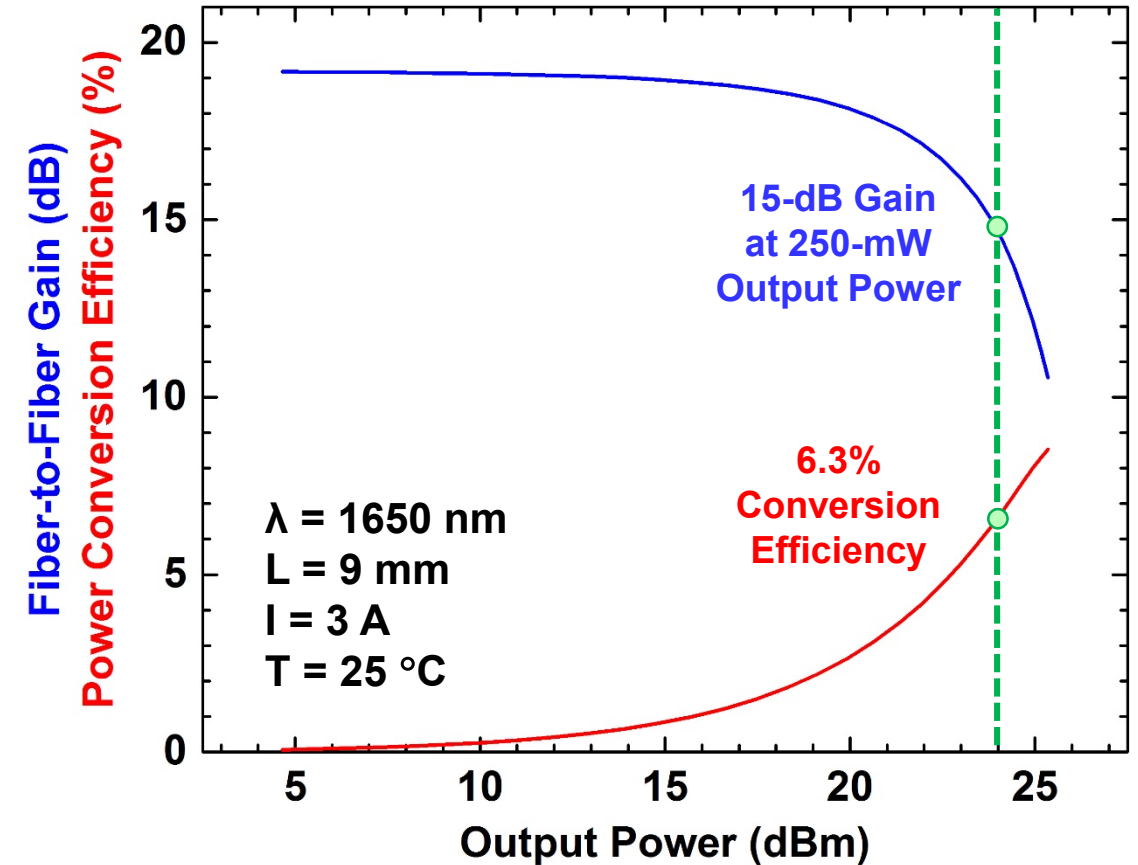


Packaged 1.65- μm SCOWA Performance

Small-Signal Gain Spectrum



Gain and Efficiency vs. Optical Power



Packaged SCOWAs provide ~12X more output power (250 mW) than prior 1.65- μm optical amplifiers



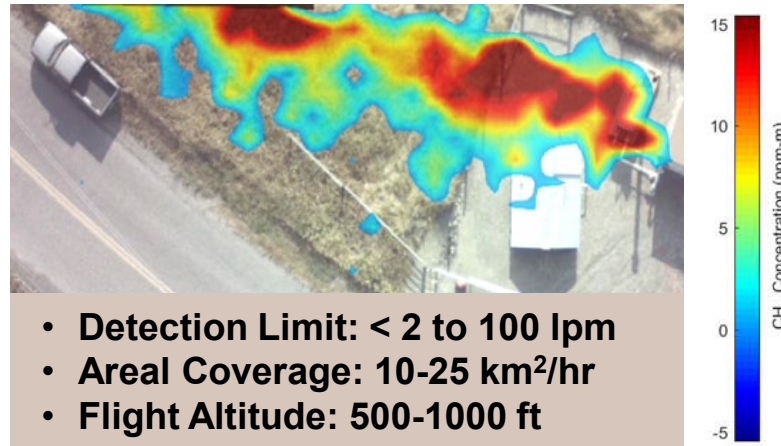
Field Demonstrations of Gas Mapping LiDAR Enabled by SCOWA Technology



Methane-Emission Mapping Demonstration (September 2017)



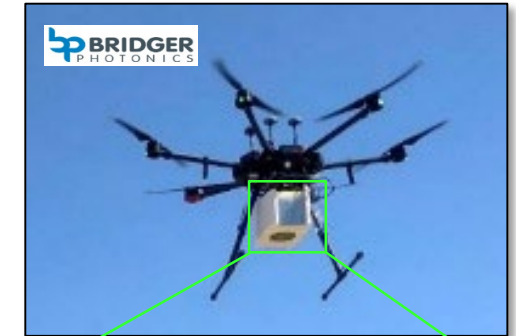
Methane (CH₄) Concentration Map



Integrated Gas Mapping Lidar
+
FMCW 3D Lidar
+
Visible Camera



2018-19 Accomplishments



- Lincoln developed 1.65-μm SCOWAs having higher output power and efficiency
- Bridger incorporated SCOWAs into drone-based GML systems
- Initiated tech-transfer CRADA



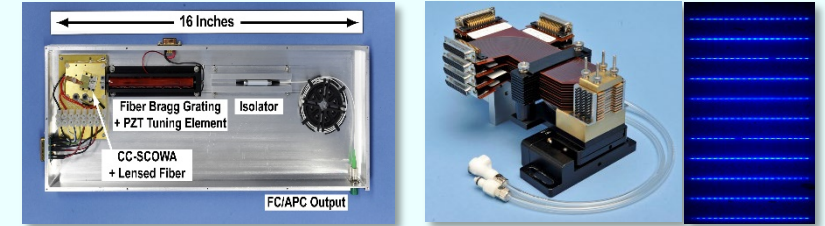
Summary and Future Directions

Fielded & Bench-Top System Demos



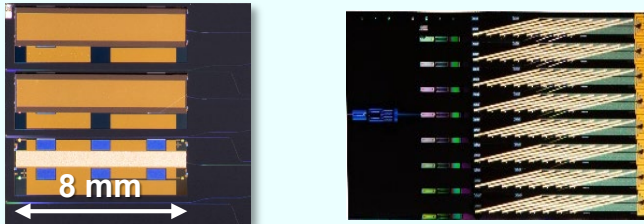
- Gas Mapping LiDAR
- Optical Communications
- Microwave Photonics
- Fiber-Optic Gyroscopes

Record-Performing Devices



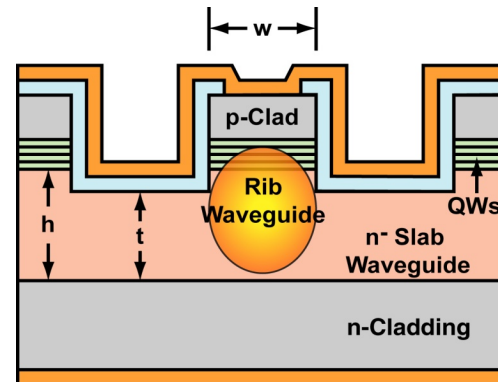
- Optical Power Amplifiers
- Mode-Locked Lasers
- External-Cavity Lasers
- Coherently Combined Lasers

Hybrid Photonic Integration



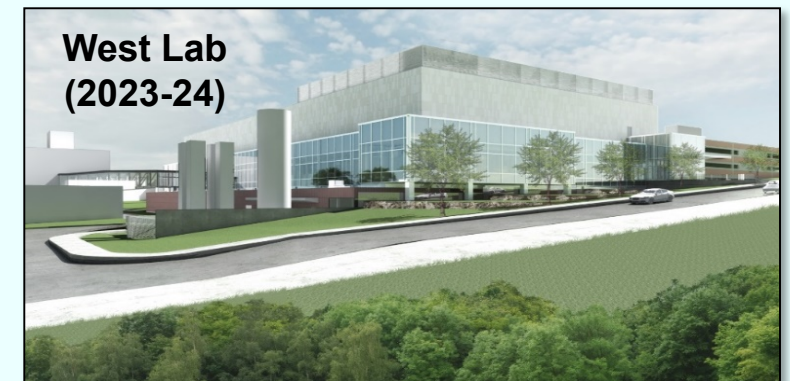
- Flip-chip bonded SCOWAs on silicon-nitride (SiN) waveguide platform
- High-power, low-noise on-chip lasers
- Direct-diode high-energy lasers (HELs)

Slab-Coupled Optical Waveguide (SCOW) Emitter



Wavelengths Demonstrated:
780, 915, 980, 1060, 1300,
1550, 1650, 2100 nm

Expanded Fabrication Resources





Acknowledgements

Lincoln Laboratory

- Joe Donnelly
- Toby Garrod (now with EpiWorks)
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- Ryan Maxson
- Antonio Napoleone
- Jason Plant
- Dominic Siriani (now with Cisco)

+

Group 82 Coating Lab

+

Compound Semiconductor
Lab (CSL) Team

+

SCOW Emitter
Development Team

Bridger Photonics

- Sam Gardner
- Stephen Gordon
- Nathan Greenfield
- Aaron Kreitinger
- Seth Kreitinger
- Helen Murphy
- Pete Roos
- Ryan Schmitt
- Eric Seger
- Michael Thorpe
- Chris Wilson

Thorlabs

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- Nathan Holley
- Thomas Landis

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