IMPRESS Lidar

Integrated Micro-Photonics for Remote Earth Science Sensing Lidar

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Outline

- Background
- Photonic Integrated Circuits (PICs)
- PIC Design: Architecture, Simulations, and Fab
- Measurements
- On-going and Future Work
NASA Science in the Near Infrared

- Near IR science allows exploration of the cosmos and offers insight into gas compositions in the atmosphere, and the health of vegetation,

- NIRSpec spectrograph on the James Webb Space Telescope

- Moderate Resolution Imaging Spectroradiometer (MODIS) on Terra and Aqua satellites
NASA’s ASCENDS Mission

Measures:
- CO2 tropospheric column
- O2 tropospheric column
- Cloud backscattering profile

~400 km polar orbit
(time of day is TBD)

Requirements for CO2 Mixing Ratio:

**Random error:** ~ 1 ppm in ~100 km along track, or
~ 0.5 ppm in ~10 sec over deserts

**Bias:** < 0.5 ppm (< 1 part in 800)

*Lower errors provide more benefit for flux est’s.*
DIAL and IPDA LIDARs enable the determination of range-resolved concentrations and column-integrated concentrations of a molecule, respectively.
• CO2 has diurnal, vertical transport. Ideally a CO2 measurement is uniformly sensitive to concentrations in the lower troposphere.
• Sampling the sides of the line where the absorption is pressure-broadened in the lower atmosphere allows measurement of a molecule under different atmospheric conditions and concentrations.
System Overview

- **Master laser**
- **Slave laser**
- **CO₂ Cell**
- **Detector**
- **EDFA**
- **MZM**
- **Bias card**
- **Pulse generator**

Transmitted laser power over time:

Frequency transmittance:

- **v₀**
- **v₁**
- **v₂**
- **v₃**
- **v₄**
- **v₅**
- **v₆**
- **v₇**
- **v₈**

Frequency offset [GHz]:

- **-20**
- **-10**
- **0**
- **10**
- **20**

Transmitted laser power:

- **1μs**
- **133μs**
Photonic Integrated Circuits (PICs)

- Eliminate interconnect losses
- Integrate built-in test capabilities
- Reduced C-SWaP and complexity
- Better electronic performance
- Miniature references
- CubeSats

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<th>Existing Technology</th>
<th>IMPRESS Lidar</th>
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<tr>
<td>Rack of equipment</td>
<td>Fully integrated PIC-EIC</td>
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<tr>
<td>- PLL electronics</td>
<td>- Photonic seed module</td>
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<tr>
<td>- Control electronics</td>
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</tr>
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</tr>
<tr>
<td>Photonic components</td>
<td>- Electronic amplifiers</td>
</tr>
<tr>
<td>- Seed module</td>
<td>- Compact all-fiber gas reference cell</td>
</tr>
<tr>
<td>- Optical amplifiers</td>
<td>- Footprint = 1.8 cm x 1.8 cm</td>
</tr>
<tr>
<td>Herriott gas reference cell</td>
<td></td>
</tr>
<tr>
<td>1 m</td>
<td>10 cm</td>
</tr>
<tr>
<td>0.25 m</td>
<td></td>
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<tr>
<td>Compact all-fiber gas reference cell</td>
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[Image of PICs and CubeSat reference]
PIC Transmitter

- Photonic integrated circuit includes:
  - C-Band Tunable SG-DBR Laser
  - Semiconductor Optical Amplifier (SOA)
  - Dual Drive Mach-Zehnder Modulator (MZM)
  - Electro-absorption Modulator (EAM)

- Straight-forward non-coherent detection with a delay line interferometer
- RZ improves sensitivities of optically preamplified receivers over standard DPSK.

Fridlander, et al., "Photonic integrated transmitter for space optical communications," Proc. SPIE 10910, Free-Space Laser Communications XXXI, 1091026 (20 March 2019);
Photonic Integrated Circuits

- Master DFB
- Slave DS-DBR
- EDFA
- Phase Modulator
- Intensity Modulator
- 20 GHz Photoreceiver
- Couplers & MMIs
Simulations

Split ratio depends on coupler length

QWI

OQW
Mirror Simulations

DBR/DBR

Front DBR reflectivity (R1)
Back DBR reflectivity (R2)

SGDBR/SGDBR

Front SG-DBR reflectivity (R1)
Back SG-DBR reflectivity (R2)

R1*R2
Fabrication

80 nm

AFM scan

\( \lambda/4 \)-shift

DFB

Multimode interference coupler

20 μm

Directional coupler

10 μm

5 μm

10 μm
Fabricated Devices

**Fabricated PIC**

- SGDBR slave laser
- DFB master laser
- Directional coupler
- 2x2 MMI
- Mach-Zehnder modulator
- SOA
- Photodiode
- Detector

**Sampled-grating DBR laser**

- Back mirror
- Gain
- Front mirror
- SOA
- Mach-Zehnder modulator

- 685 μm
- 500 μm
- 290 μm
- 500 μm

**High-speed photodiode**

- BCB

**Quarter-wave-shifted DFB**

- 500 μm
- 350 μm
Measurements Diode Lasers

Light-Current-Voltage Curves
Measurements Diode Lasers

Lasing Spectrum

- 51.6 dB SMSR

Tuning with Stage Temperature

- 500 μm
- 350 μm

SOA  DFB
Measurement Setup

- Measurement with bench-top equipment
Multi-stage electrical design effort to:
• Reduce system footprint
• Improve system performance by reducing signal delay and loss in the feedback loop
• Allows use of closely placed high-speed (20 GHz) TIA
• Should simplify overall system complexity.
• Offers path towards co-packaged microwave and photonic circuits