# Narrow-linewidth distributed feedback semiconductor lasers operating at 2 μm

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***Long-Wavelength Diodes and Cascade Lasers (MB1)***
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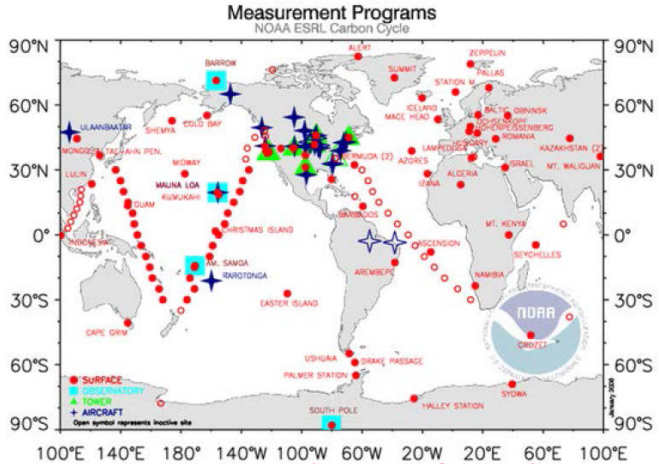
# Understanding the role of $CO_2$ in climate change

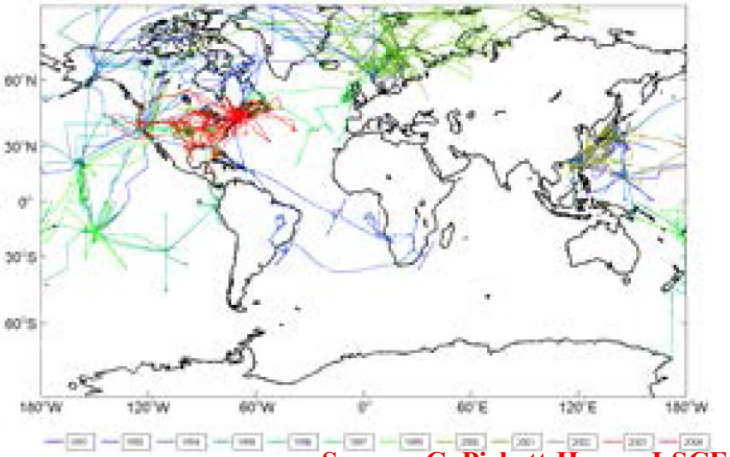
## Ground-based networks




Source: NOAA-ESRL

- Point measurements, sparse coverage
- Longest $CO_2$ measurement (continuous since 1957)
- Observation from surface ~500m
- High temporal resolution, accuracy and precision

## Air-craft Campaigns

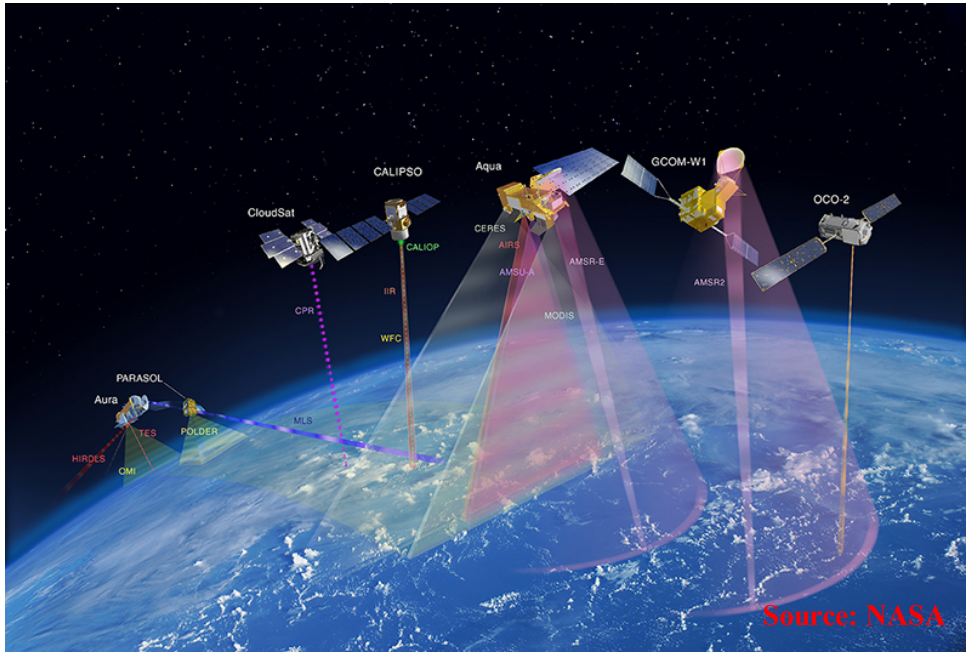



Source: C. Pickett-Heaps, LSCE

- Regional measurements
- Infrequent flights/ operations
- Varying altitudes accessible
- Vertical profiles
- High accuracy and precision

# Watching the Earth breathe: monitoring $CO_2$ from space

The earth observing system afternoon constellation(**"A-train"**)




Space-borne platforms are extending the atmospheric $CO_2$ record by providing high quality measurements with unprecedented coverage and density in space and time.

Currently installed systems are passive systems. These systems rely on reflected light from sun, therefore have inherent limitations

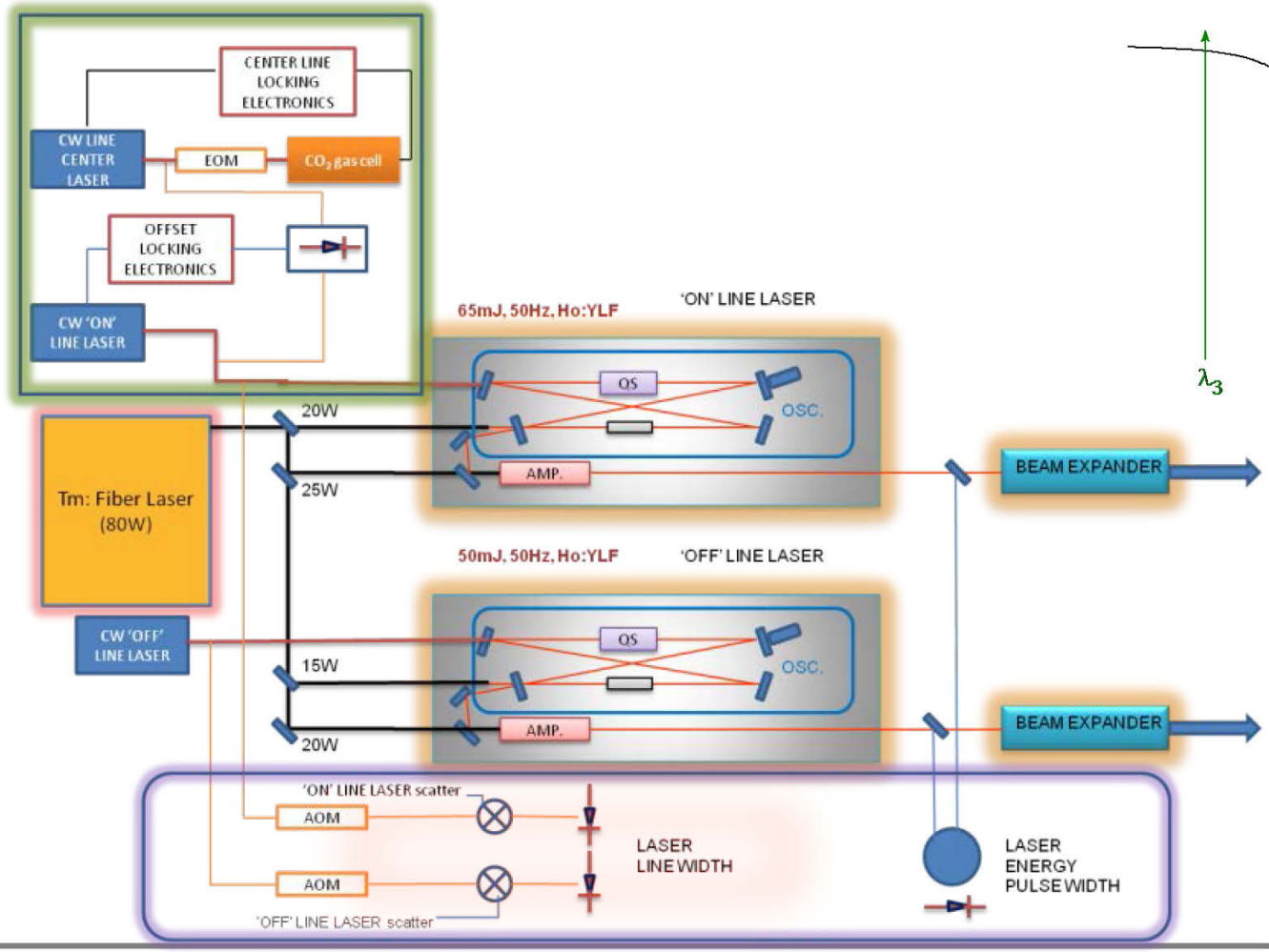
- Variable sensitivity at different solar angles
- Inability to observe high altitude targets during local winter
- Limited SNR over oceans due low surface reflectivity

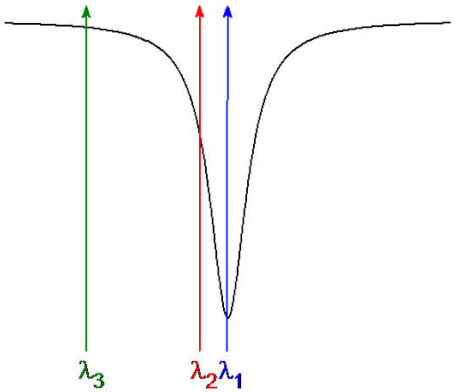
**An active scheme using lidar remote sensing would allow monitoring of $CO_2$ emission over nights, days and seasons to produce $CO_2$ measurements without seasonal, latitudinal, or diurnal bias.**

# Active remote $CO_2$ monitoring

## Laser Absorption Spectrometer

Integrated path differential absorption (IPDA)

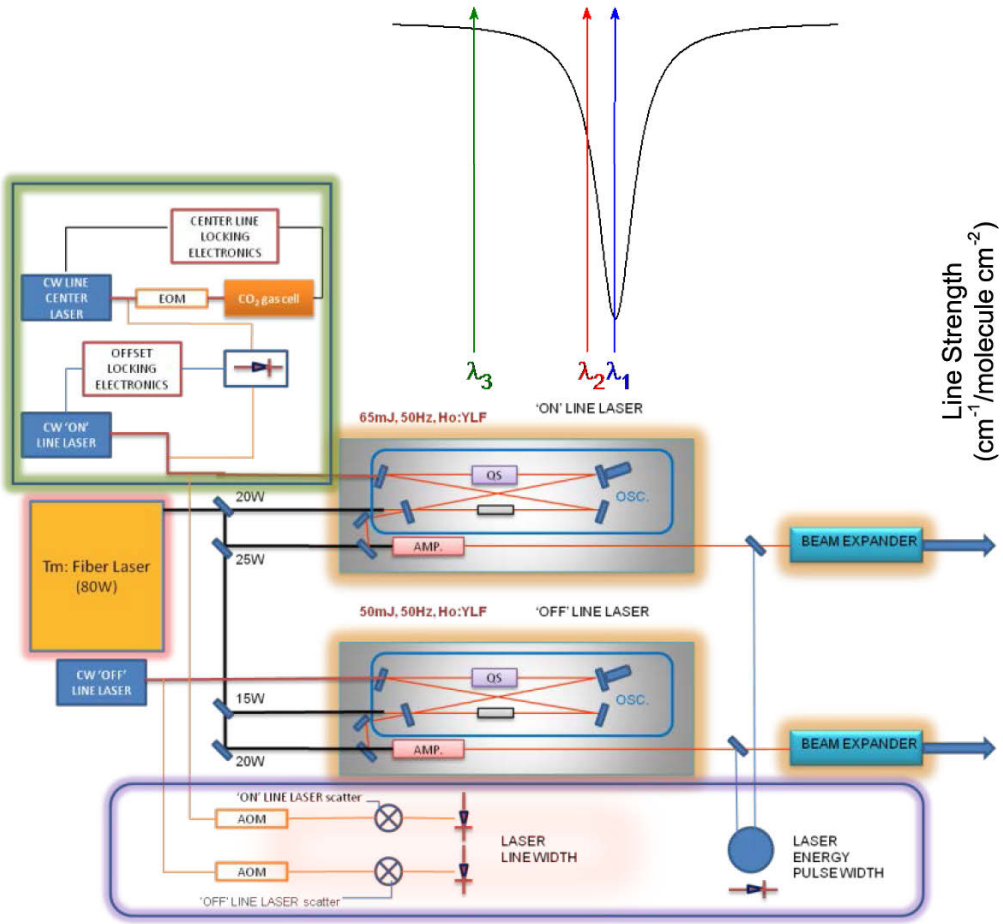


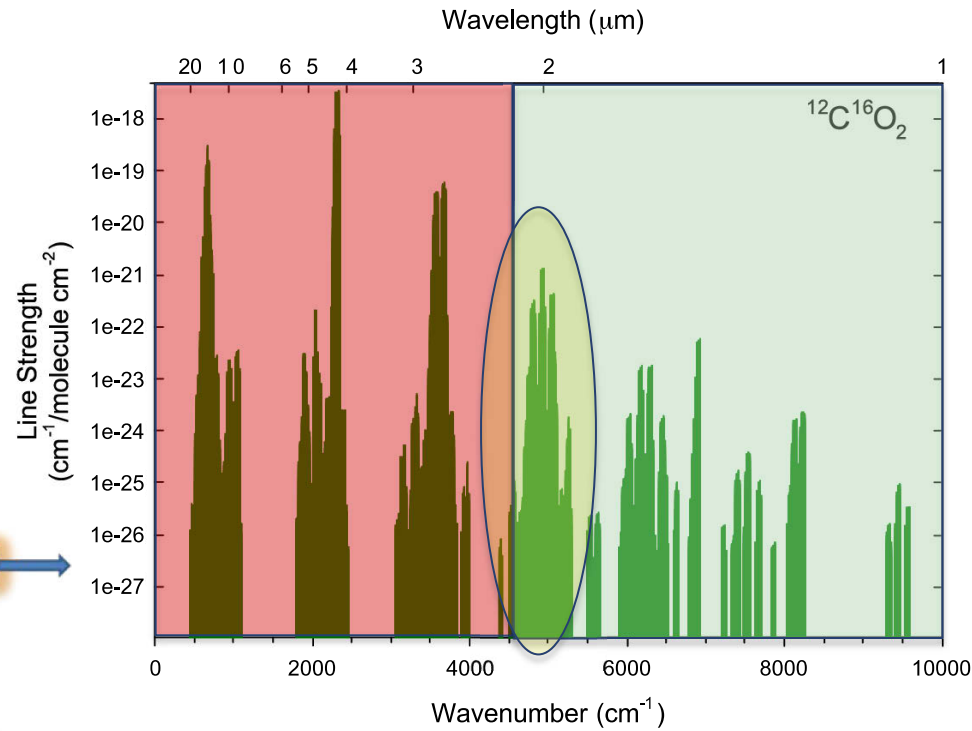
# Active remote $CO_2$ monitoring

## Laser Absorption Spectrometer

Integrated path differential absorption (IPDA)




$CO_2$ molecular absorption spectra




Single-frequency narrow linewidth lasers at 2.05 μm for $CO_2$ lidar systems

# Semiconductor DFB lasers for 2.05 μm lidar systems

Fiber lasers and solid state lasers

- ✓ High output power
- ✓ Long coherence length ( narrow linewidth)
- ✓ Circular beam ( $M^2 \sim 1$)
- x Bulky
- x Low efficiency
- x High maintenance costs
- x Reliability issues
- x Large thermal budget

Unsuitable for airborne and space-borne applications

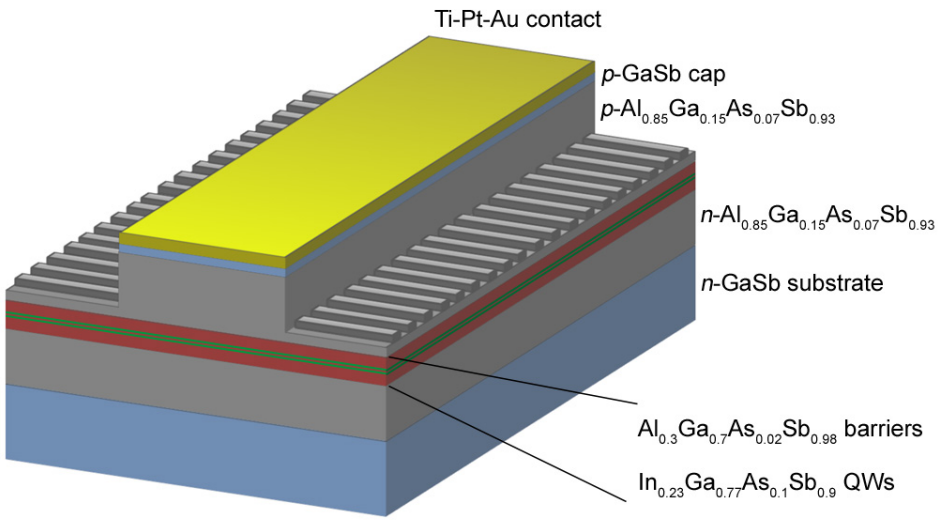
Distributed feedback semiconductor lasers

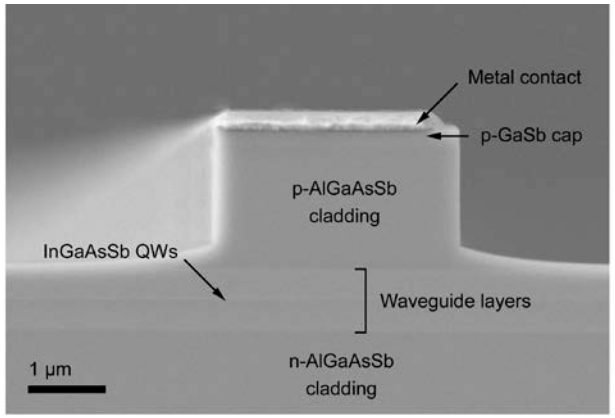
- ✓ Compact
- ✓ High efficiency
- ✓ Better reliability
- ✓ No moving parts ( less susceptible to vibrations)
- ✓ Low maintenance cost
- x Lower output power
- x Larger linewidth
- x Poor beam quality ( $M^2 > 1$)

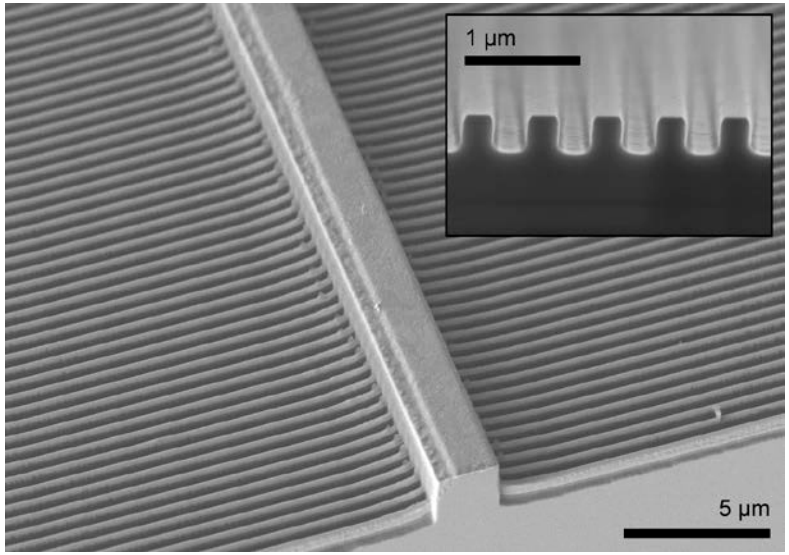
- ➢ >30 mW fiber-coupled output power
- ➢ < 100 KHz linewidth
- ➢ < 1MHz frequency stability

# Laterally coupled DFB lasers @ 2μm

Schematic drawing of laterally coupled DFB laser

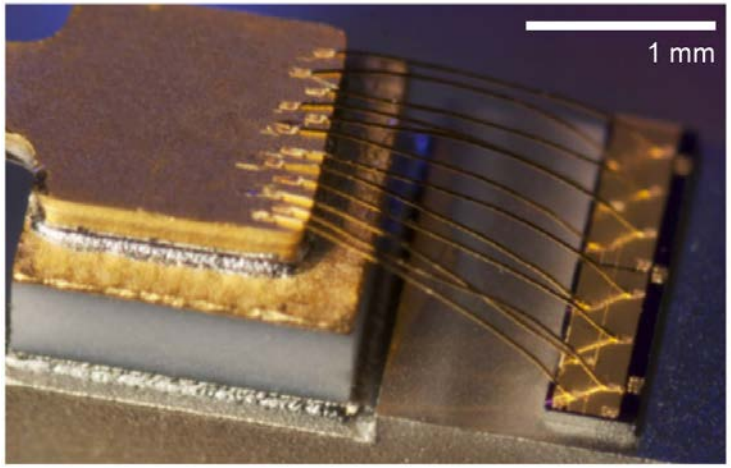



- Single-mode optical waveguides are etched into low-index cladding layer
- Second order gratings are etched along side ridges

# Laser chips: test and measurements

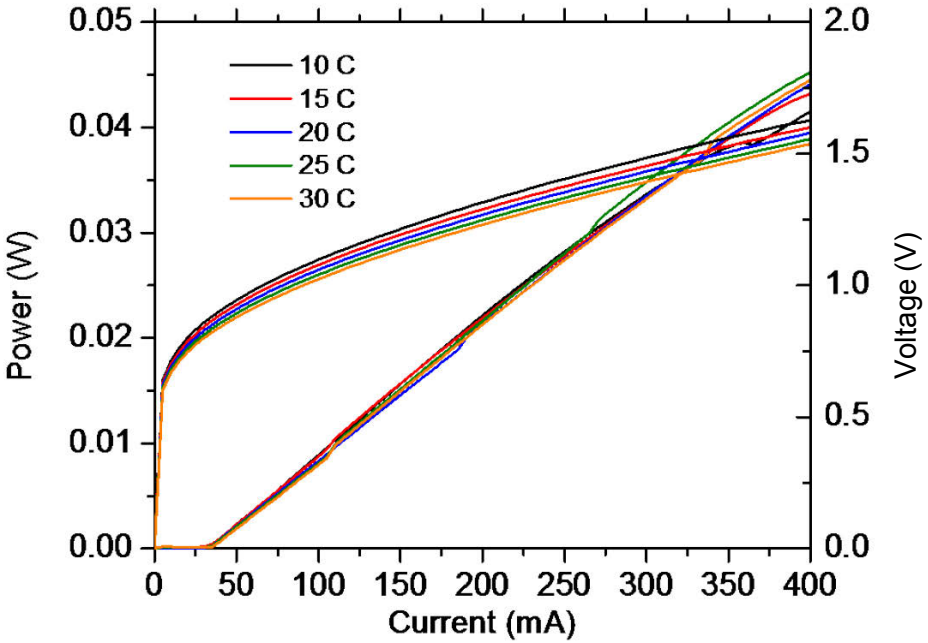



Devices are cleaved into 2 mm long bars

The facets are coated AR/Passivated ( front/back)

Mounted on gold plated submounts and wire-bonded

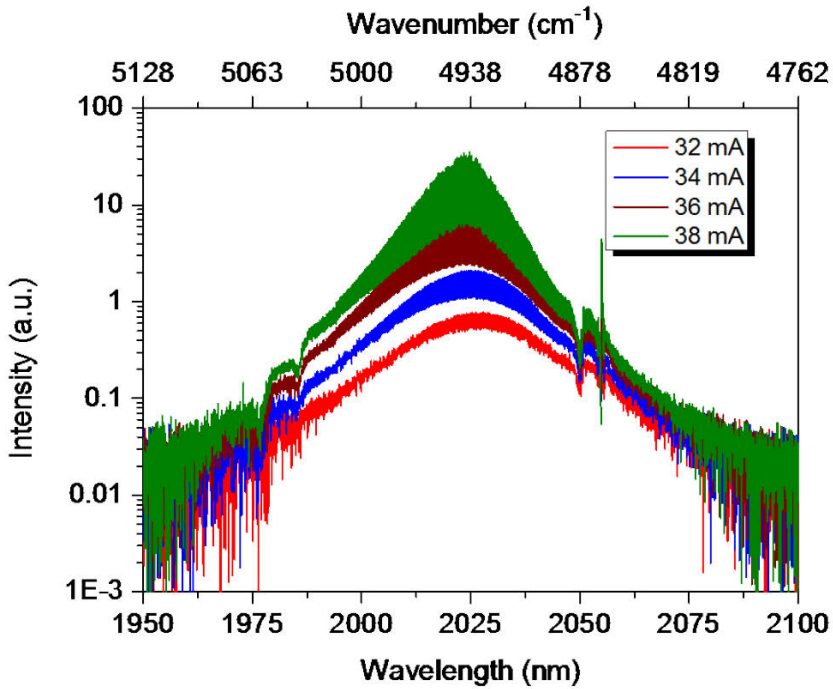
LIV curve for a mounted laser measured at different temperatures



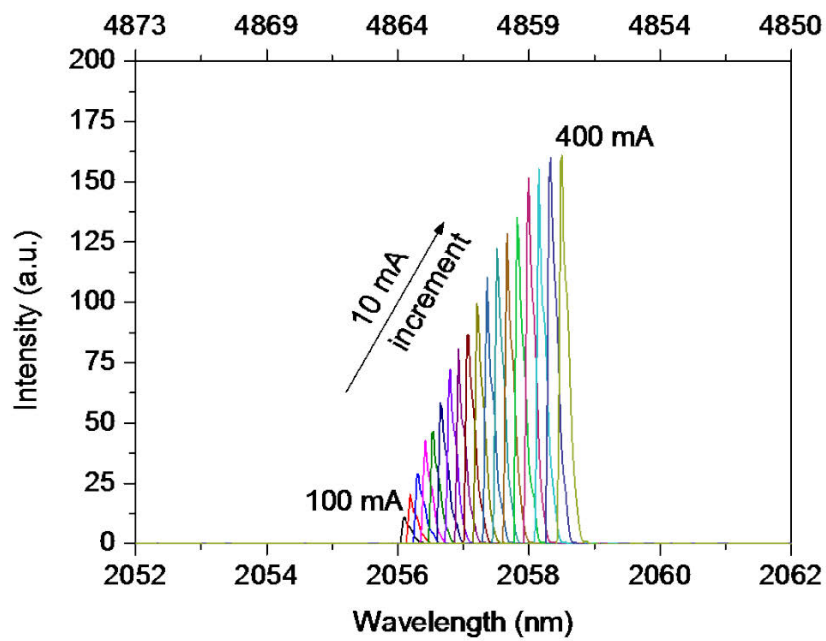

small temperature dependence

# Electroluminescence and lasing spectra

Sub-threshold electroluminescence spectra




Measured lasing spectra at 10 C




Gain peak is offset from the DFB lasing wavelength: Allow for DFB operation at higher currents before spurious FP modes show up in the lasing spectrum.

# Linewidth measurement techniques

**Heterodyne technique**

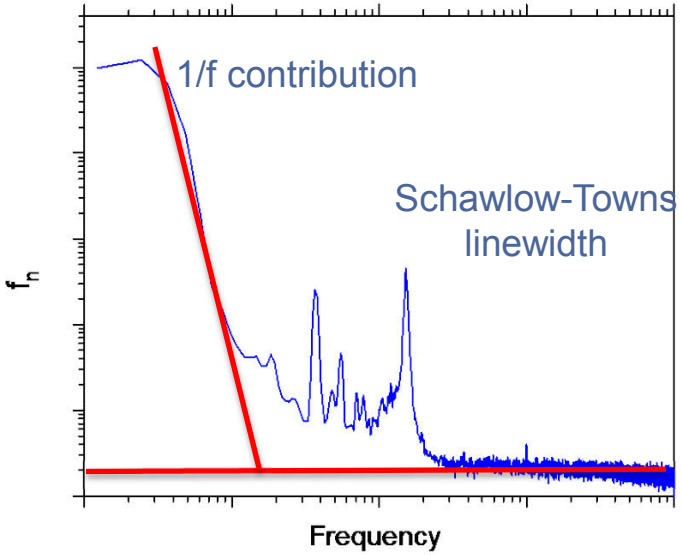
- Beat two similar laser with small frequency offset and look at the beating spectrum
- Relatively simple to implement
- Requires very stable lasers to minimize frequency drift

**Frequency noise spectra**

- Convert frequency fluctuations into amplitude fluctuations
- Detect amplitude fluctuation
- Frequency noise spectrum contains linewidth data

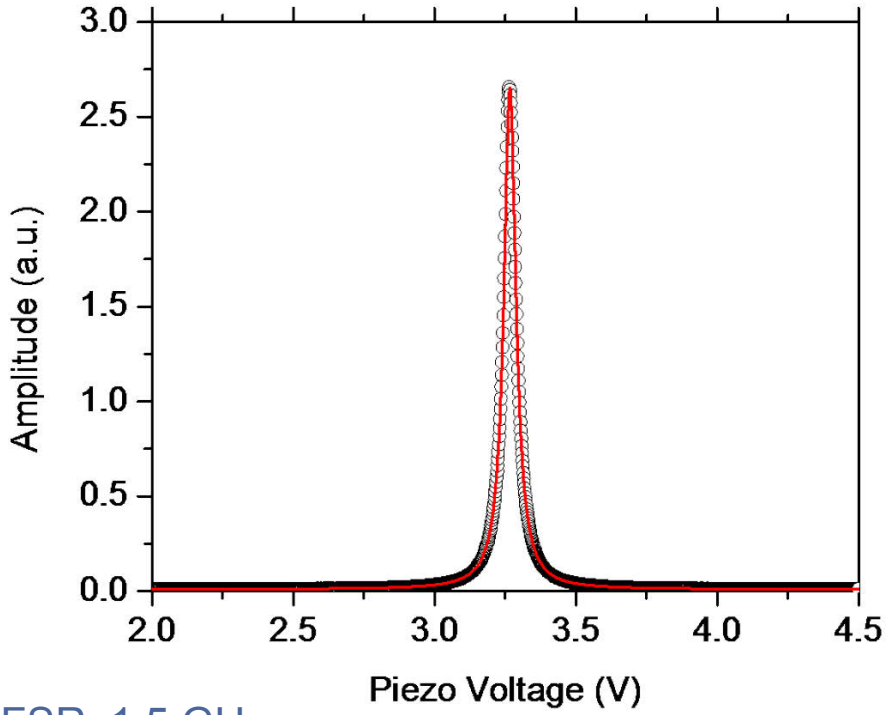
**Self-delayed homodyne technique**

- Beat one laser with its delayed replica
- Requires long (>20 km) of single mode optical fiber ( not readily available at 2 μm)
- Is insensitive to frequency jitter



# Frequency to amplitude conversion

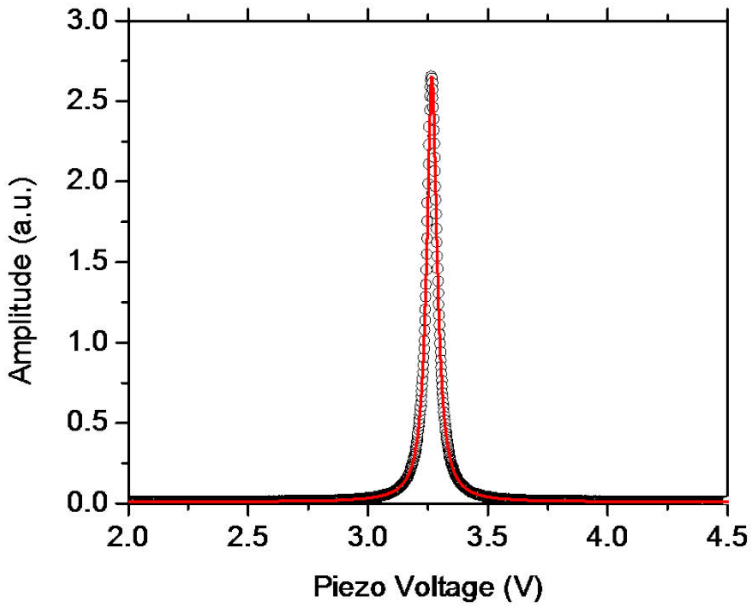
Scanning Fabry-Perot interferometer transmission at laser fixed current



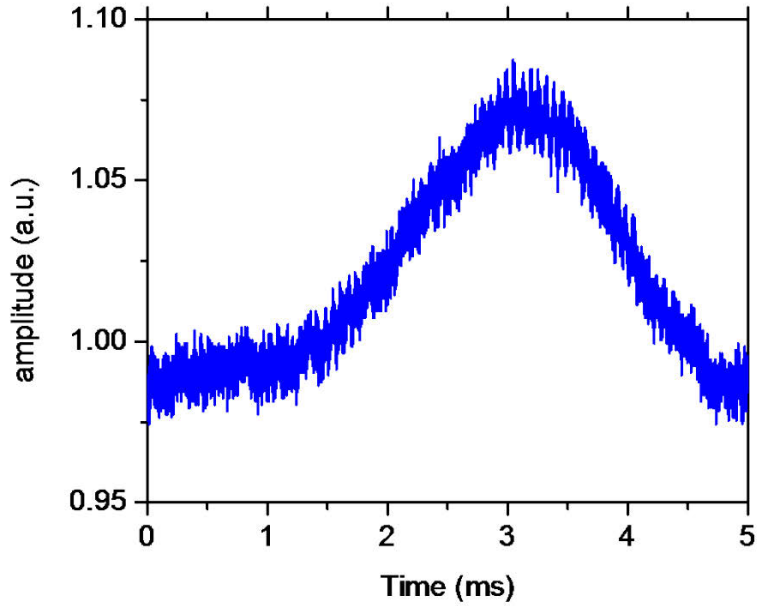

Fabry-Perot FSR: 1.5 GHz
Resonance quality factor: 250

# Frequency to amplitude conversion

Scanning Fabry-Perot interferometer transmission at laser fixed current



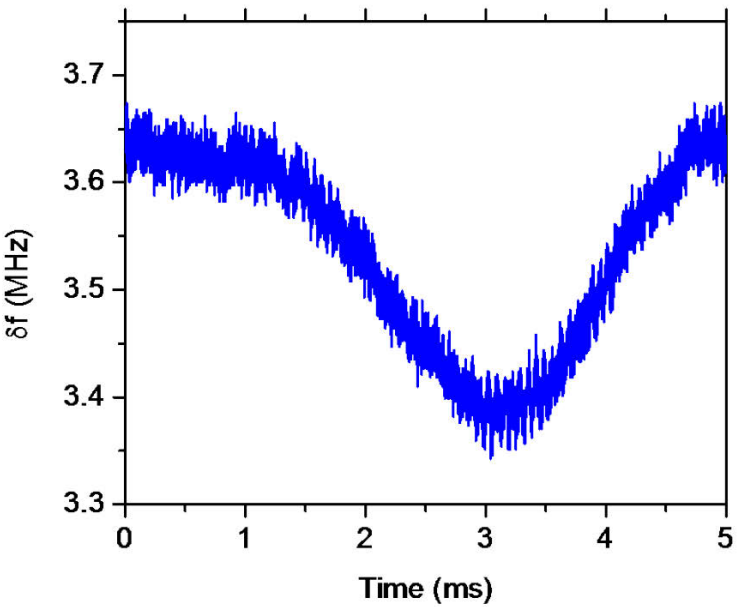

Converted frequency fluctuations into amplitude fluctuations



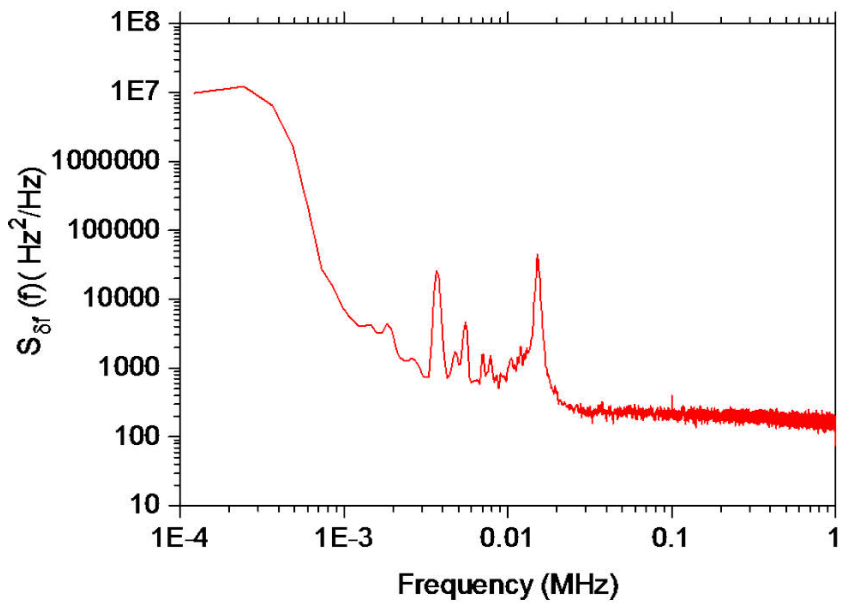

By biasing the interferometer on one if its transmission slopes, frequency deviations are converted into amplitude fluctuations.

# Frequency to amplitude conversion

Calibrated frequency fluctuations




Power spectral density of frequency fluctuations

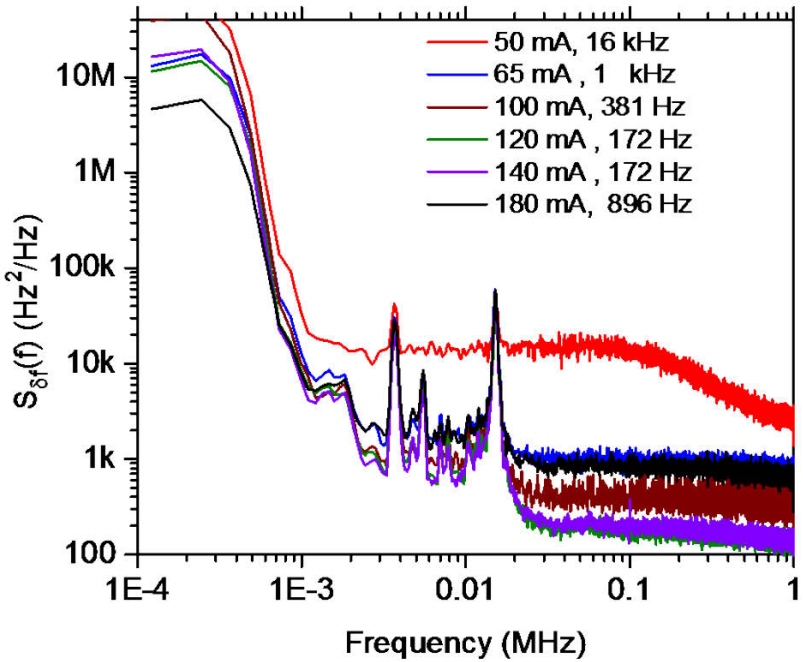



Power spectral density function has laser linewidth data and reveals contributors to the overall laser lineshape profile

The spurious peaks between 1-20 KHz arise from the piezo element resonances

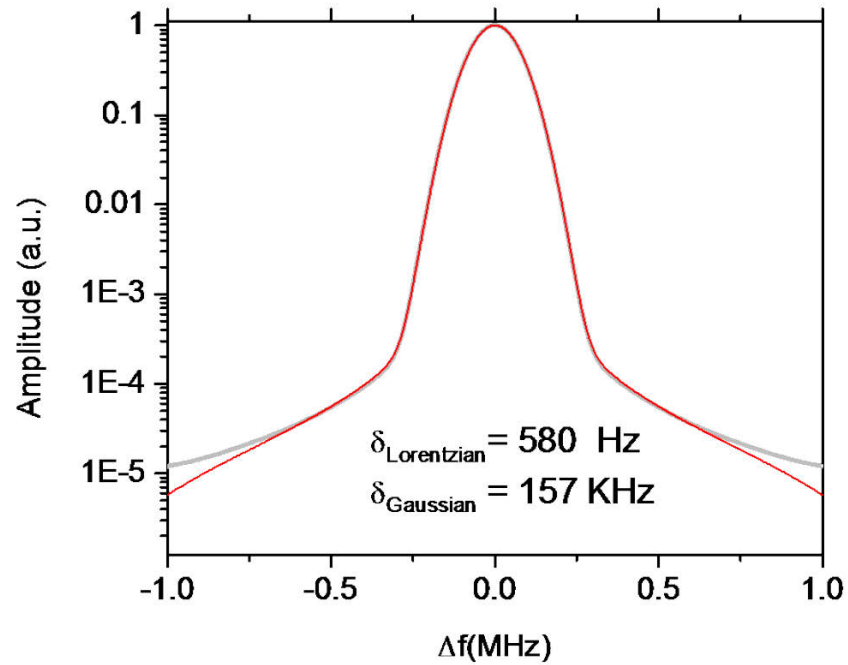
# Measured frequency noise spectrum

Measured frequency noise spectrum at different injection currents




Schawlow-Townes linewidth contribution decreases with increasing power before it rebroadens at current s above 120 mA

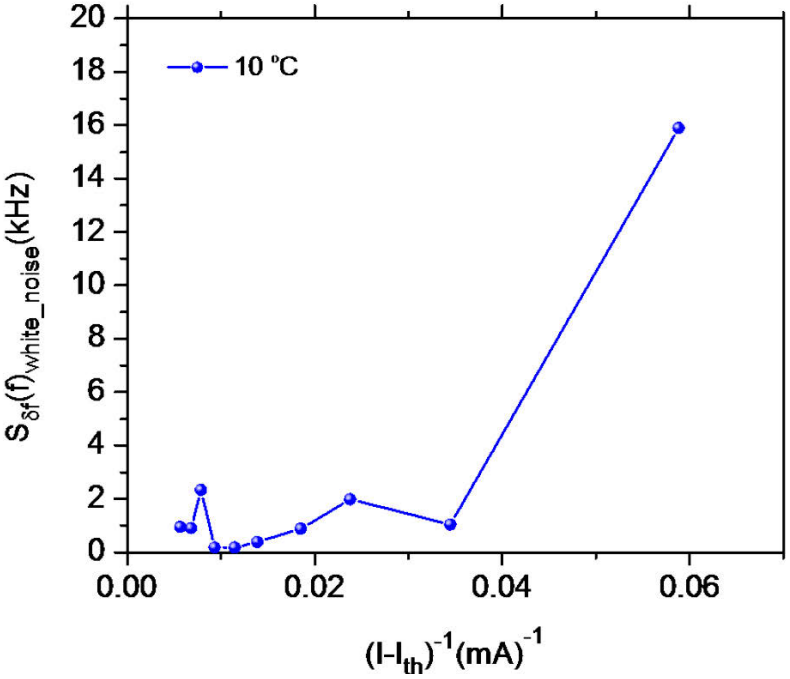
Estimated laser lineshape with a Voigt profile fit

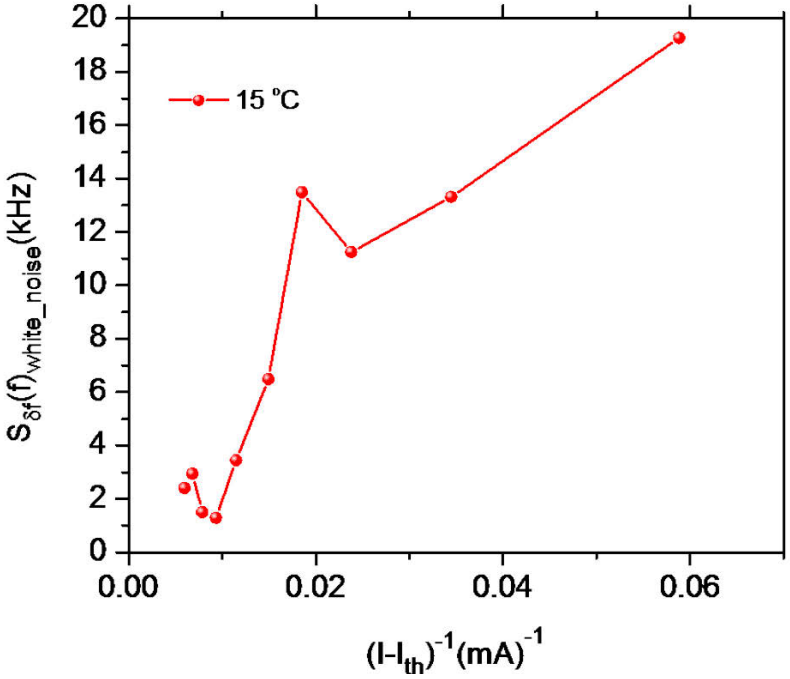



Voigt profile with Gaussian contribution dominating the lineshape describes laser lineshape.

# Laser linewidth vs. injected current

Schawlow-Townes laser linewidth versus inverse of injected current above threshold

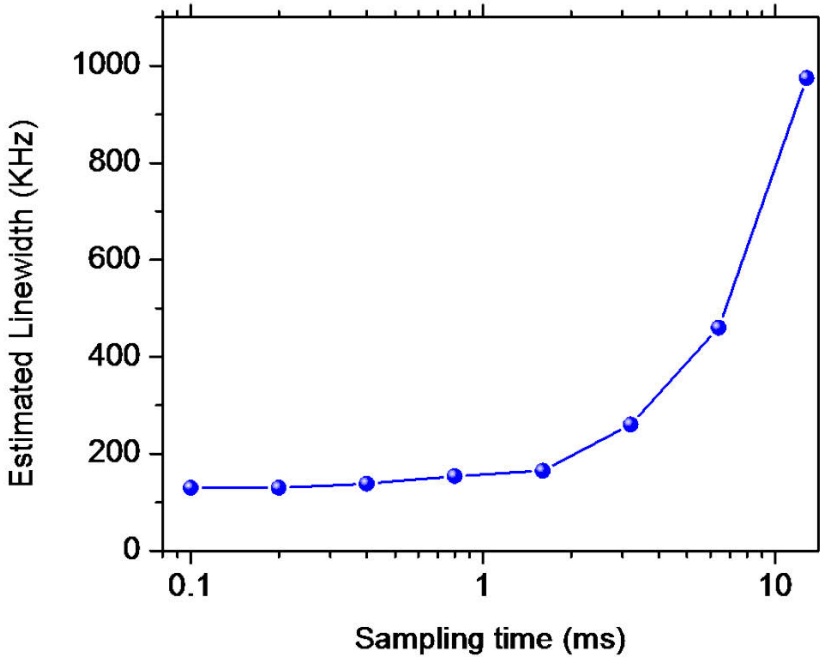


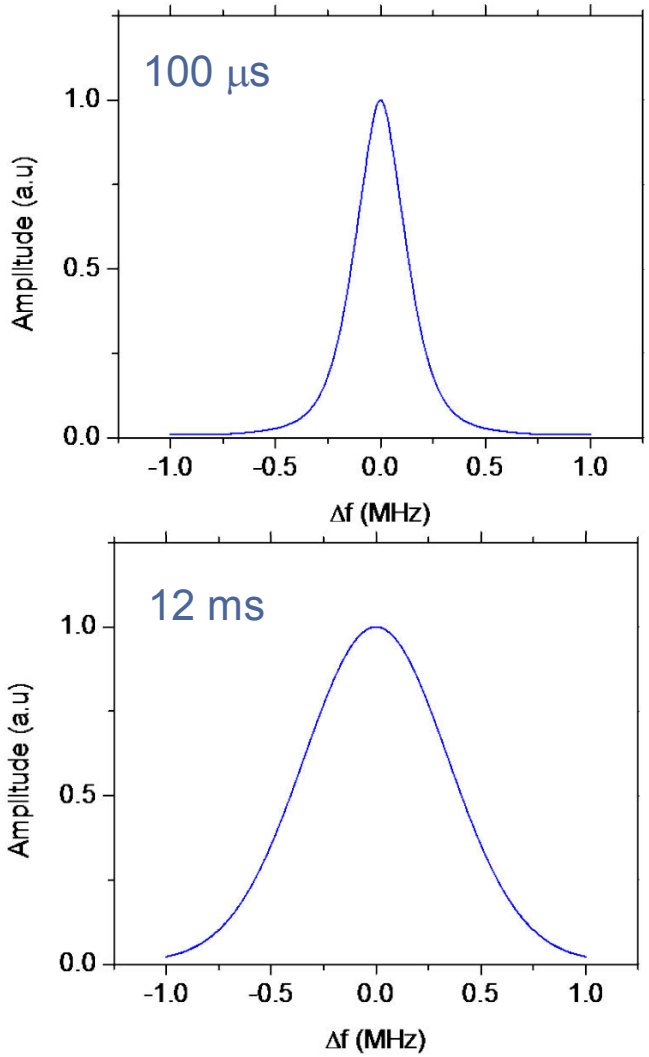




Laser linewidth increases at higher temperature due to change in gain peak detuning and increase in linewidth enhancement factor ($\alpha$)

# Linewidth-measurement time

Estimated laser linewidth versus measurement time




For measurement times longer than 1 ms (>1 KHz bandwidth), average 1/f fluctuations set the upper limit for laser linewidth

# Summary

- High power DFB lasers at 2 μm wavelength range were demonstrated
- Lasers show extremely narrow Schawlow-Townes linewidth (1KHz)
- In operation, laser linewidth is limited by technical noise (1/f)
- Locking lasers to a reference cell eliminates/suppresses 1/f noise
- These performances make these lasers suitable for $CO_2$ monitoring lidar systems

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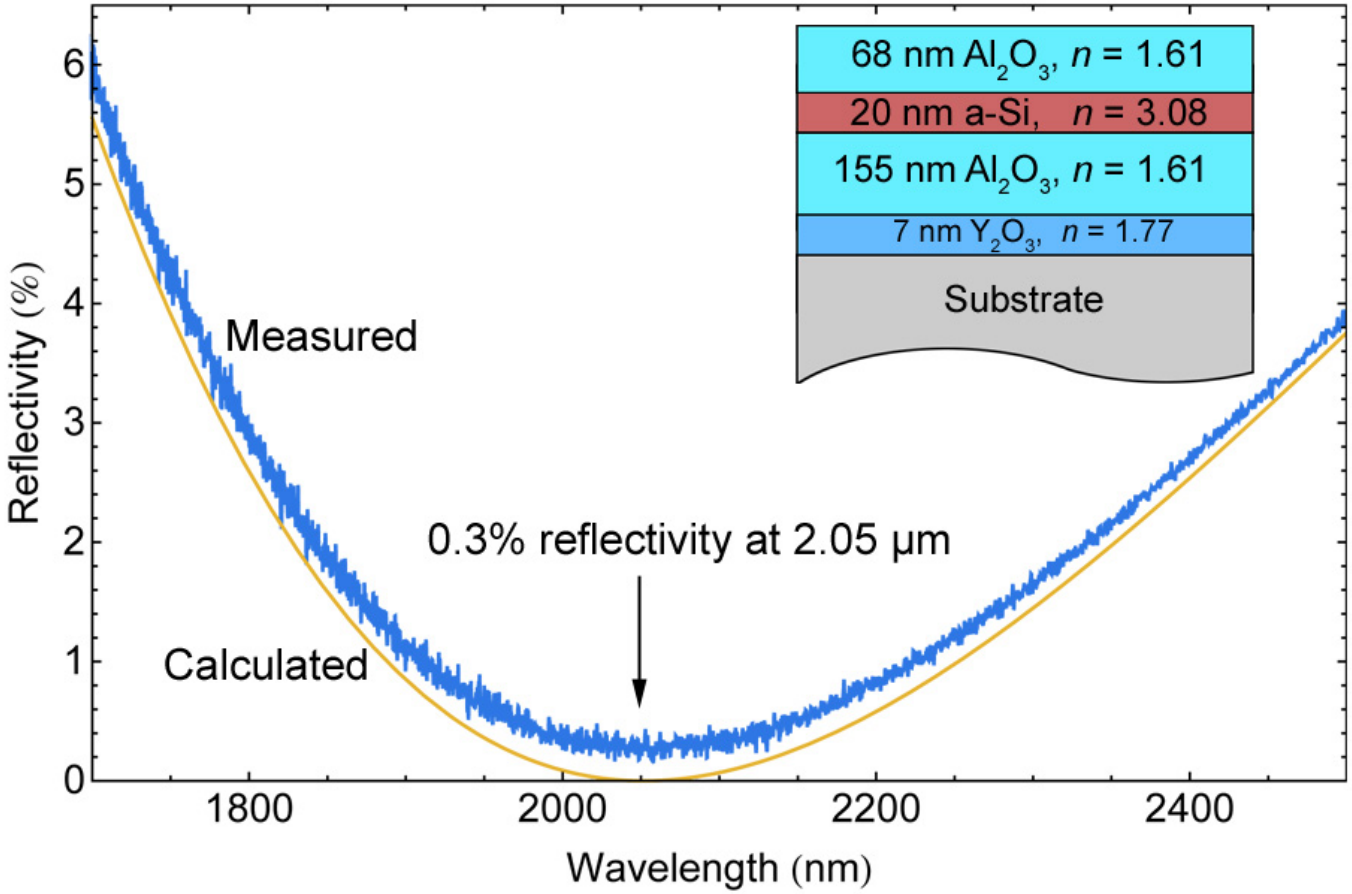
Leon Shterengas and Gregory Belenky, *Power Photonic, Inc. (Stony Brook Univ.)*

# Facet coating