High-power semiconductor lasers for in-situ sensing of atmospheric gases

Carl Borgentun
Microdevices laboratory (MDL), JPL/Caltech

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Government sponsorship acknowledged.

Outline

- Background
- Laser design and fabrication
- Performance
- Next target

Background

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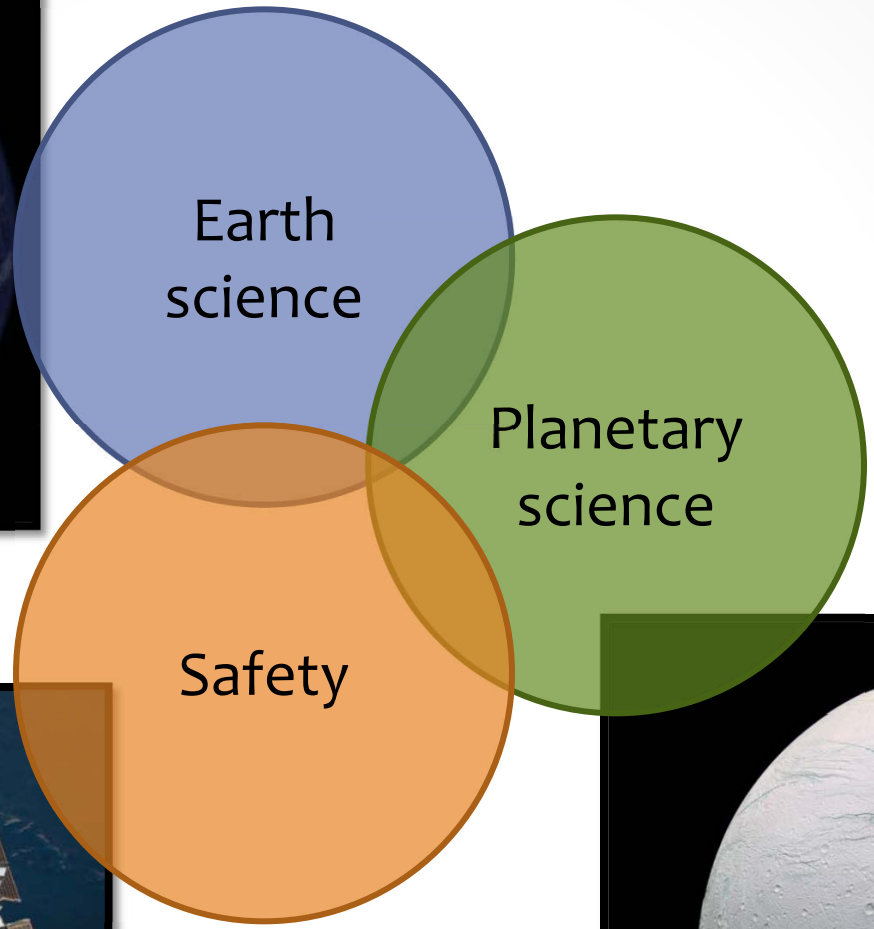
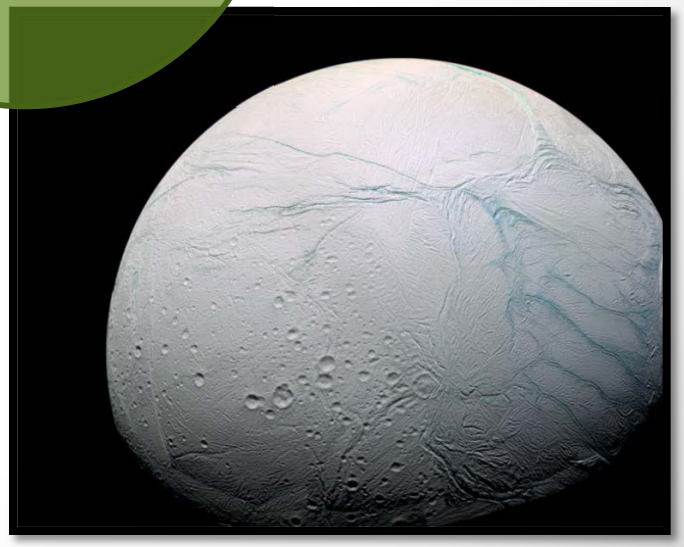
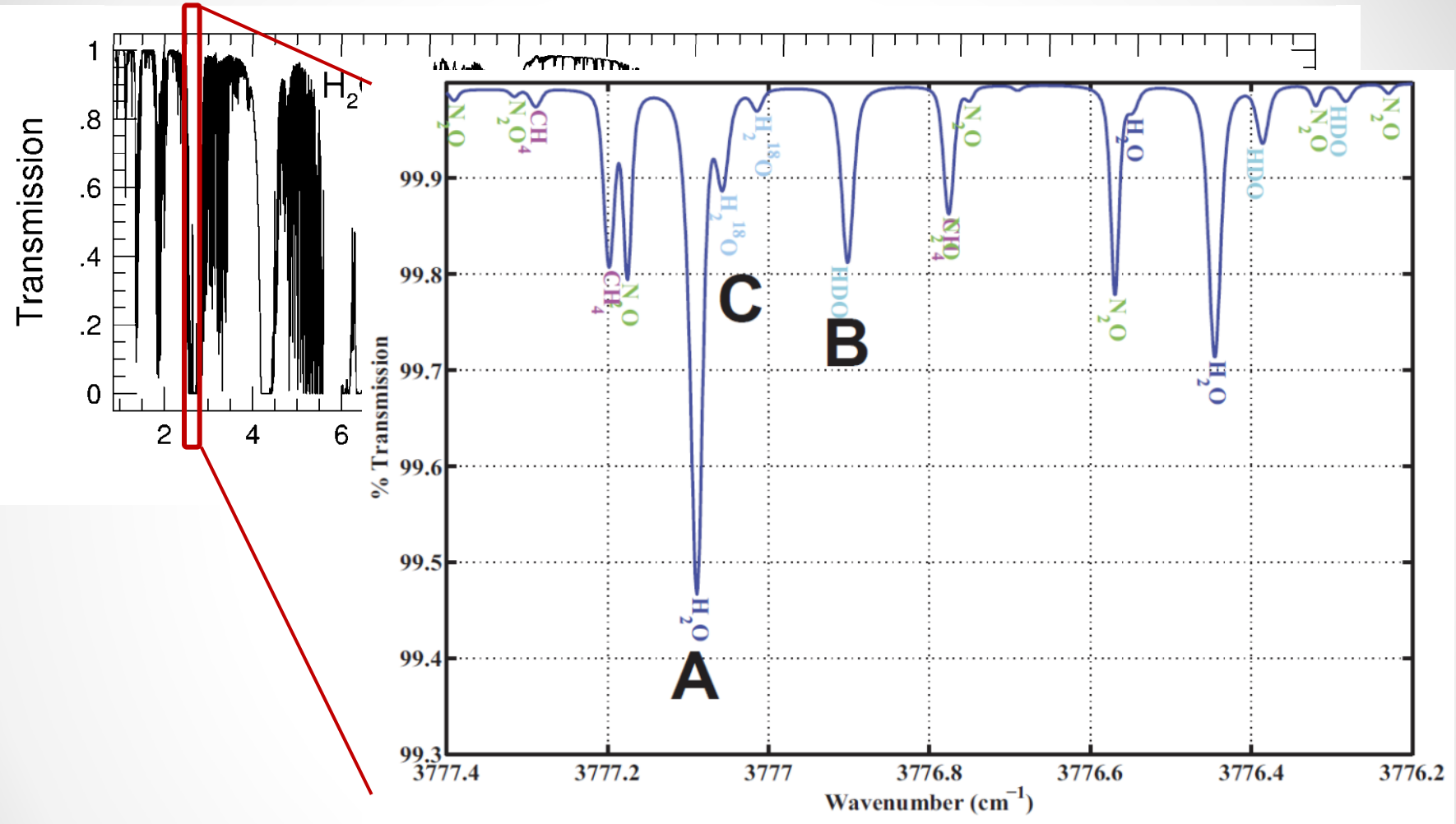
Gas sensing





Credit: NASA

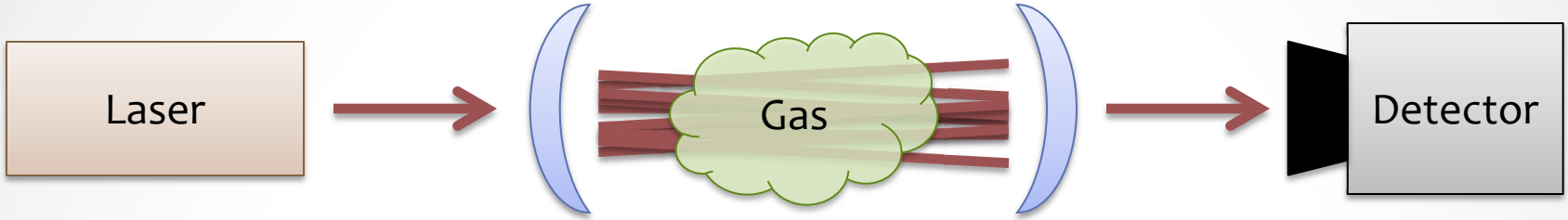
Absorption spectroscopy basics



Credit: Richard W. Pogge, Ohio state university

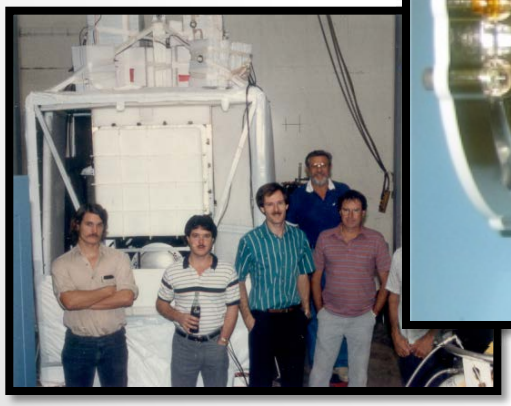
Credit: David Sayres, Harvard

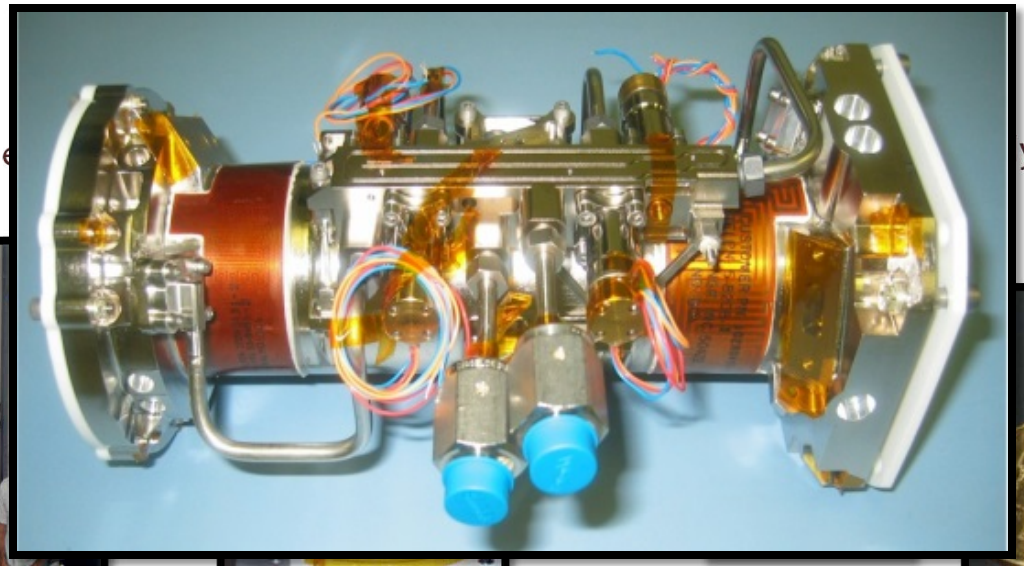
Laser spectroscopy basics

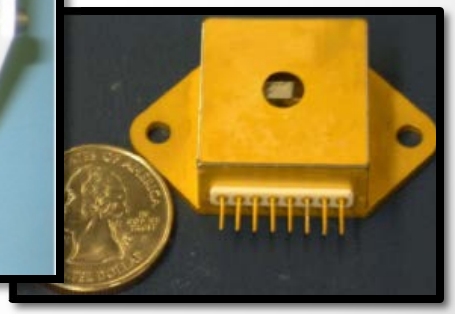


1980s

Liquid helium-cooled lase y cooled (1000kg)

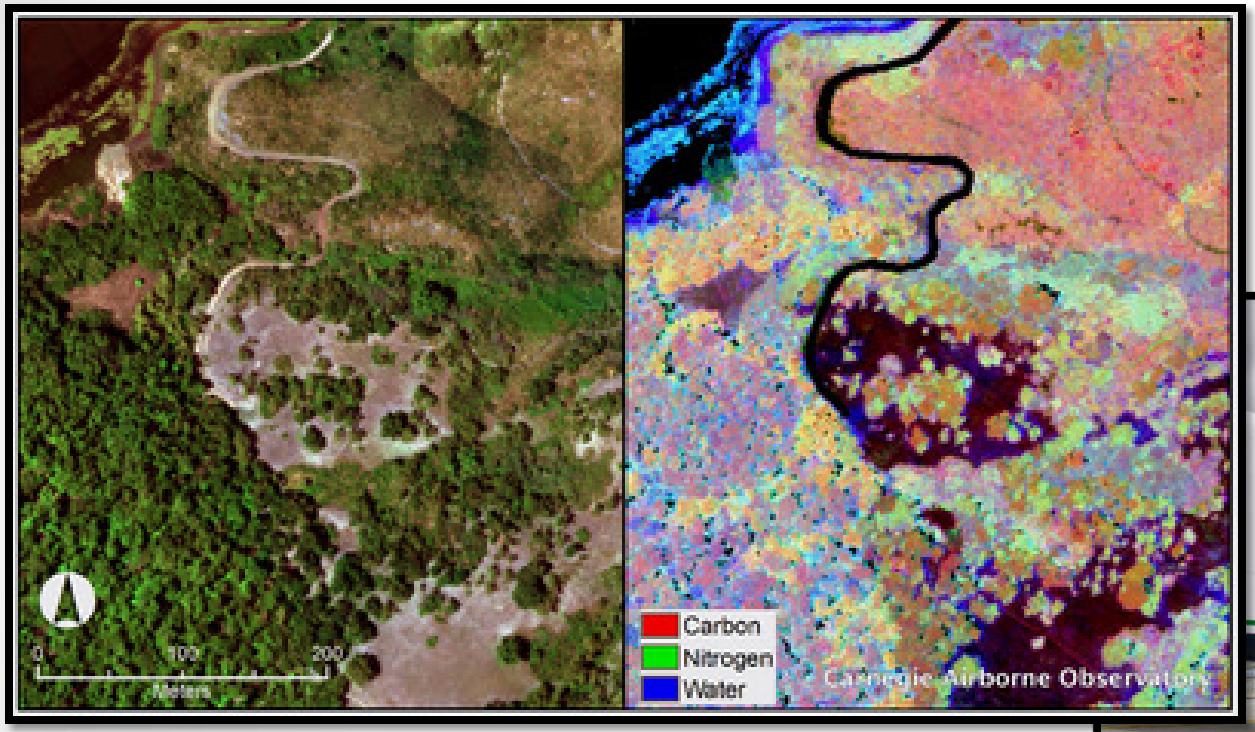






Example application – Earth science

Earth science



Carnegie airborne observatory

CARNEGIE INSTITUTION FOR SCIENCE

Credit: Carnegie institute of science

Example application – Planetary science

Mars polar lander

Mars science laboratory

Planetary science

Credit: NASA

Example application – Safety

Safety

Carbon monoxide monitoring instrument

Credit: NASA

Ozone depletion

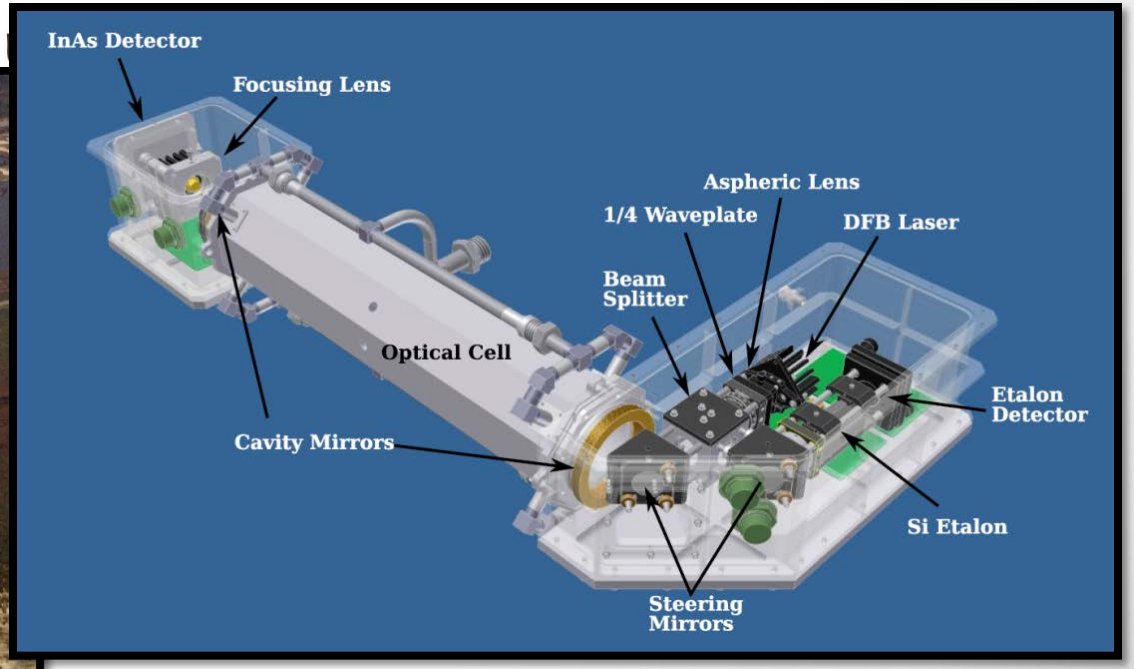
- Chlorine compounds destroy ozone, but only at cold temperatures.
- Water vapor in the stratosphere increases the threshold temperature, at which ozone destruction can take place.
- Risk of thinner ozone layer not only at the poles, but also at lower latitudes where people, animals, and plants live.
- Various explanations for high mixing ratios of water vapor, distinguishable by measuring water isotopologues.

HARVARD UNIVERSITY

James G. Anderson et al., Science, 337 (6096), 835-839, 2012.

Need for more sensitive instrument

- Traditional absorption techniques are not sensitive enough for the simultaneous measurement of water and its less abundant isotopologues.
- Jim Anderson's group at Harvard are developing a cavity-enhanced instrument.
- A high-power laser so



Credit: NASA; Jim Anderson, Harvard

Laser design and fabrication

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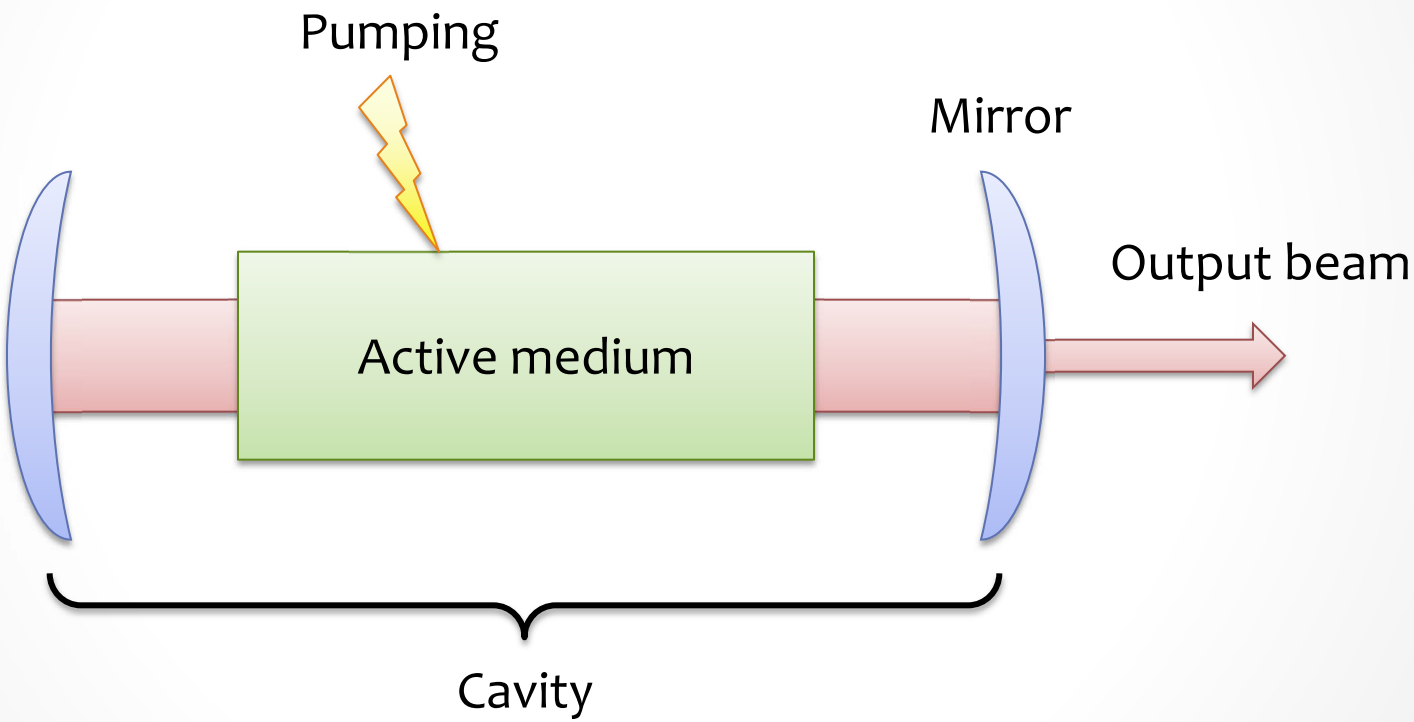
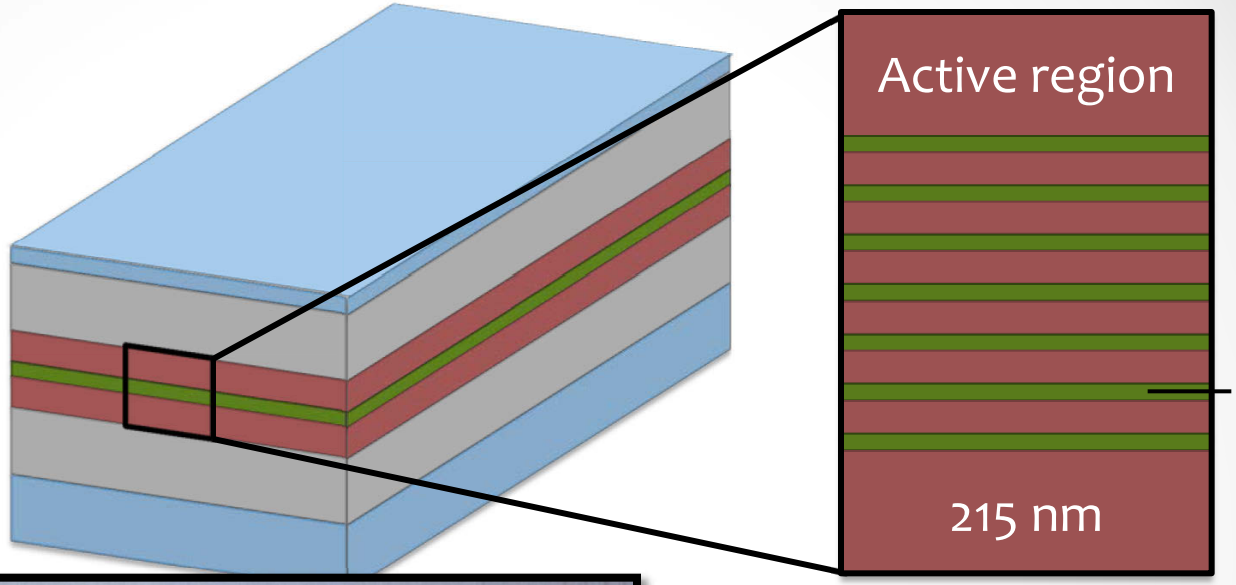
Laser crash course

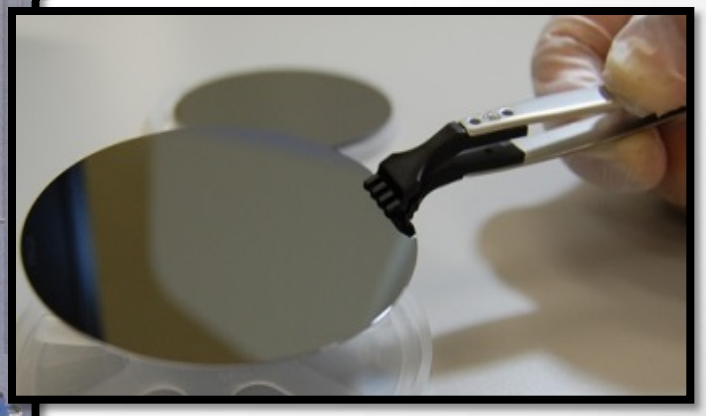
Two criteria:

- Optical gain
- Cavity



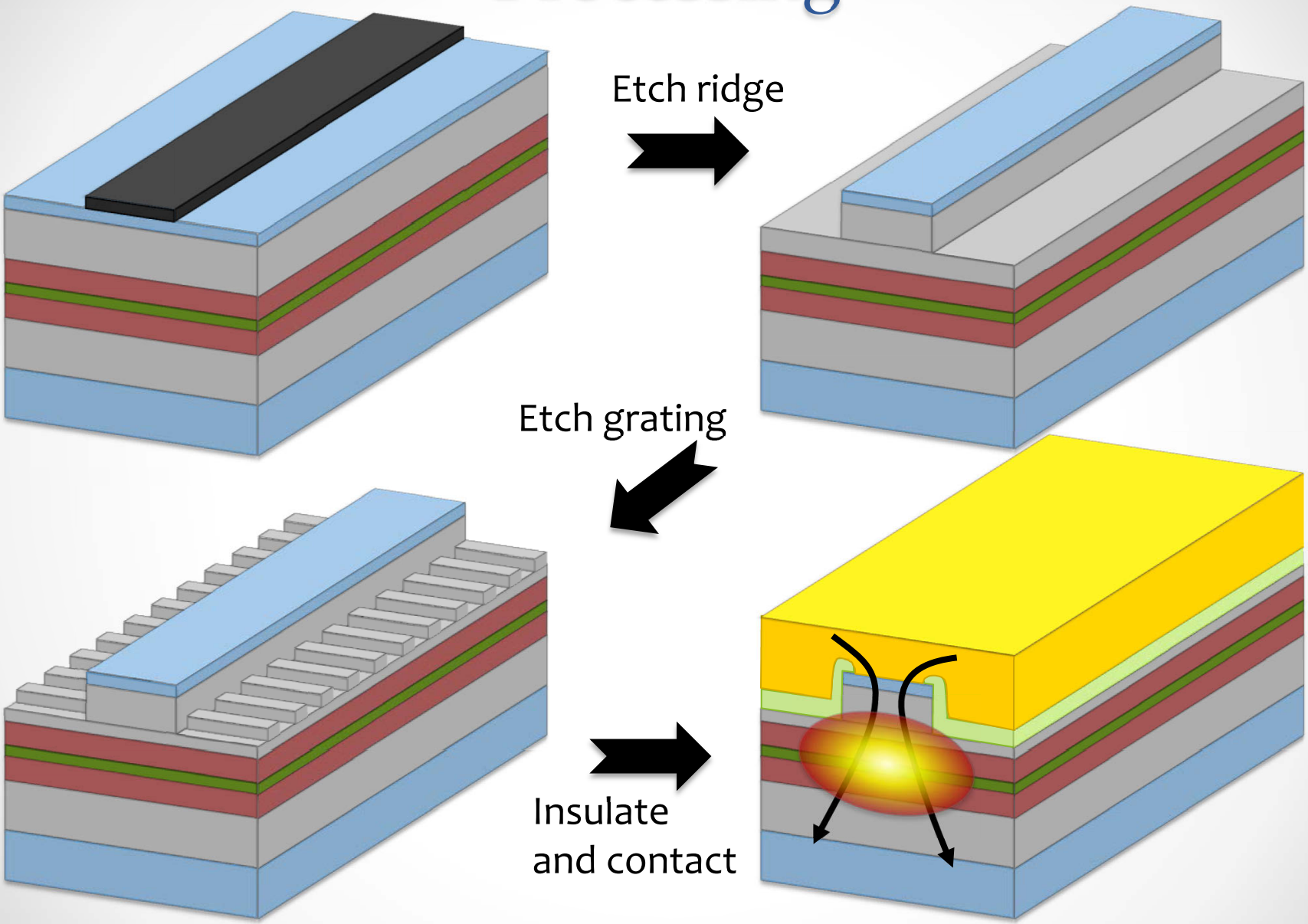
Molecular Beam Epitaxy



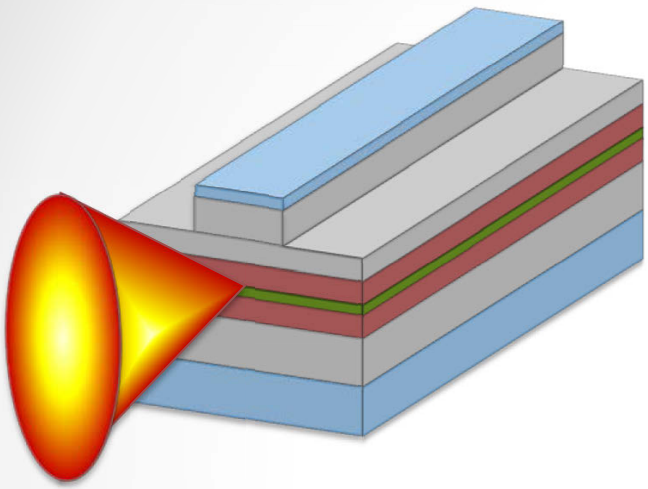


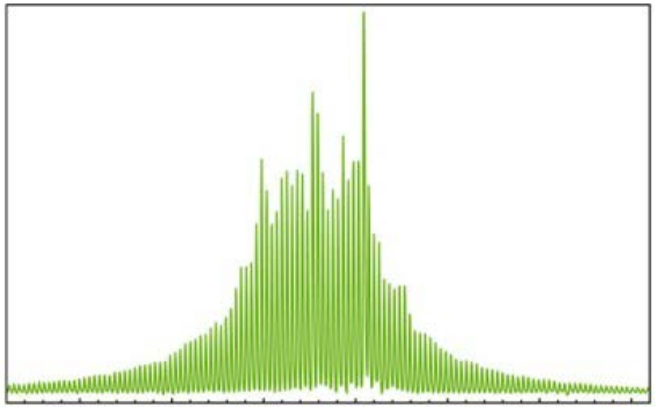
Credit: JPL

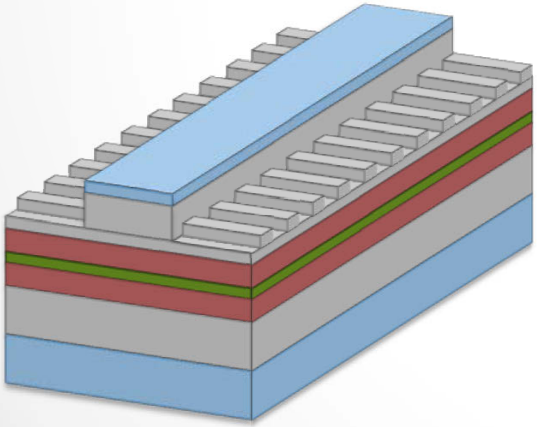
Processing

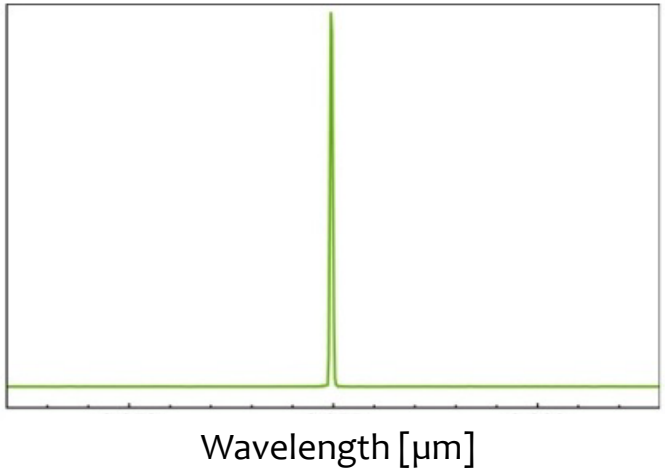


Single-mode emission



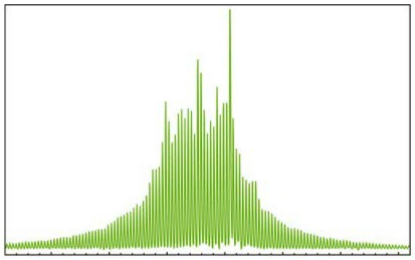


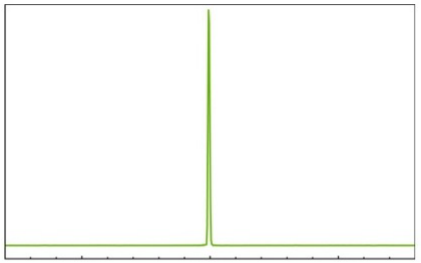


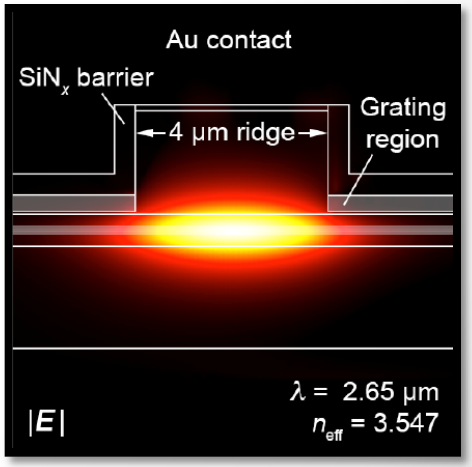


Grating

- Distributed feedback (DFB) laser using a Bragg grating => single-mode emission.
- Etched, i.e. non-metal => less loss.
- Laterally coupled => no epitaxial re-growth necessary.

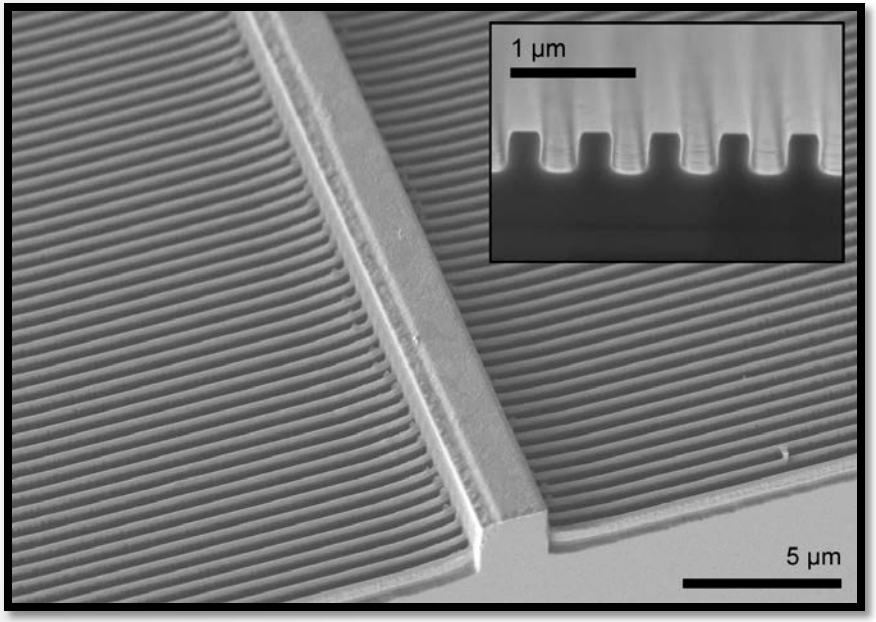


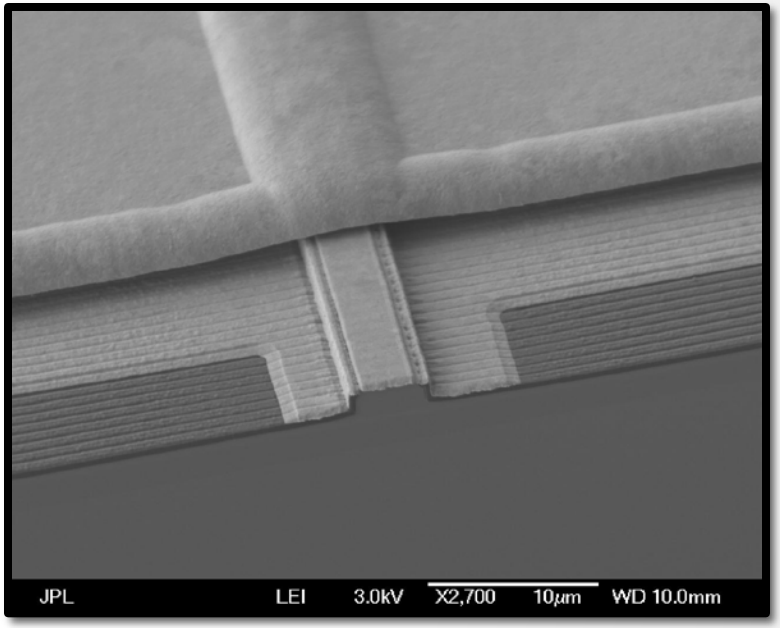




Credit: JPL

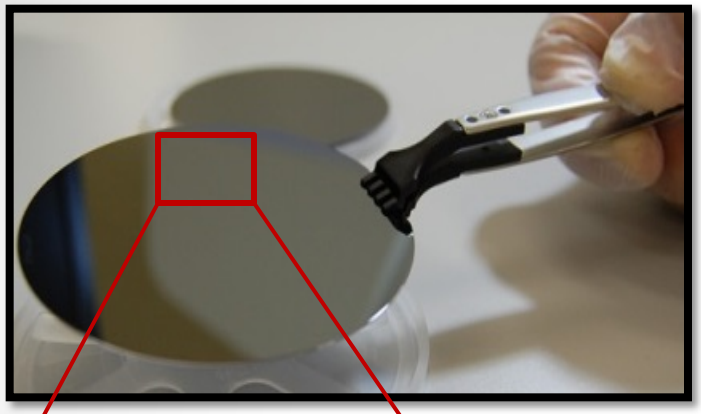
SEM pictures

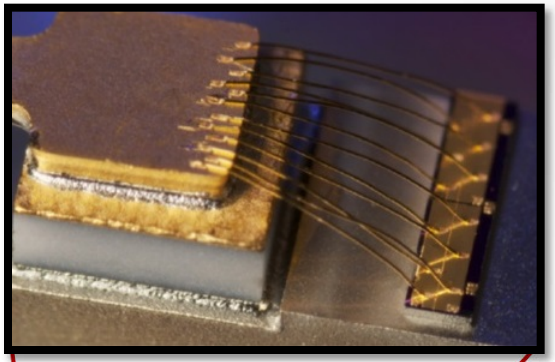




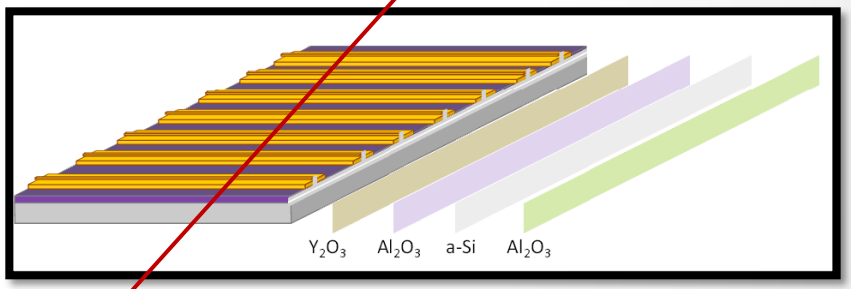
Credit: Cliff Frez

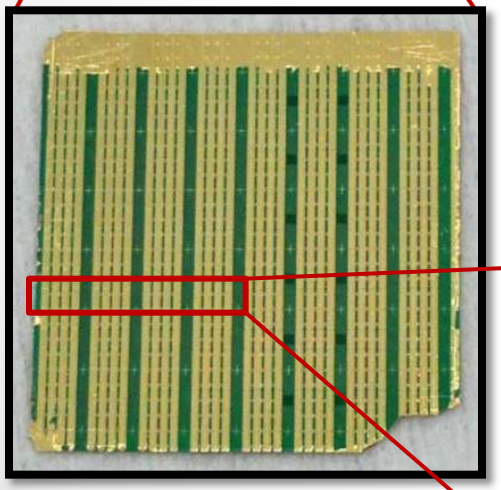
Coating, cleaving, and bonding

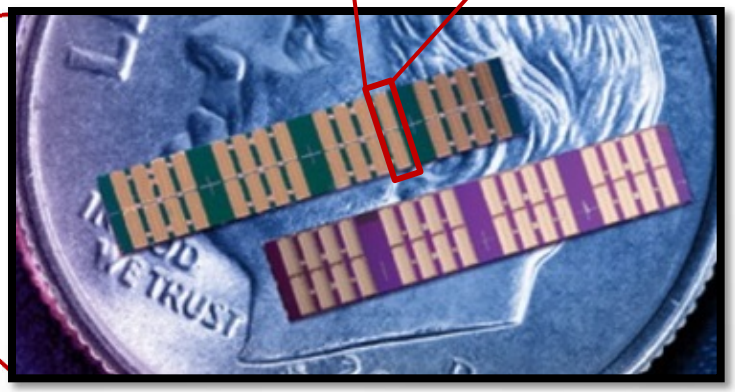




Wavelength:
2.0 – 3.5 μm







Credit: Cliff Frez

Performance

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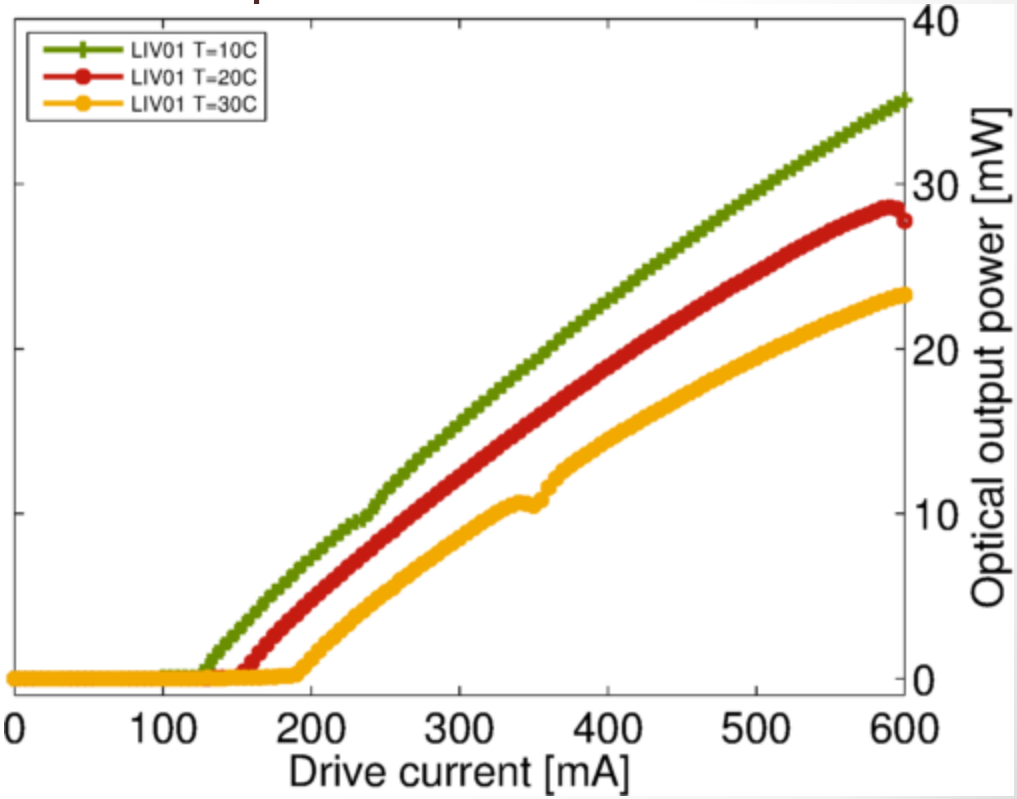
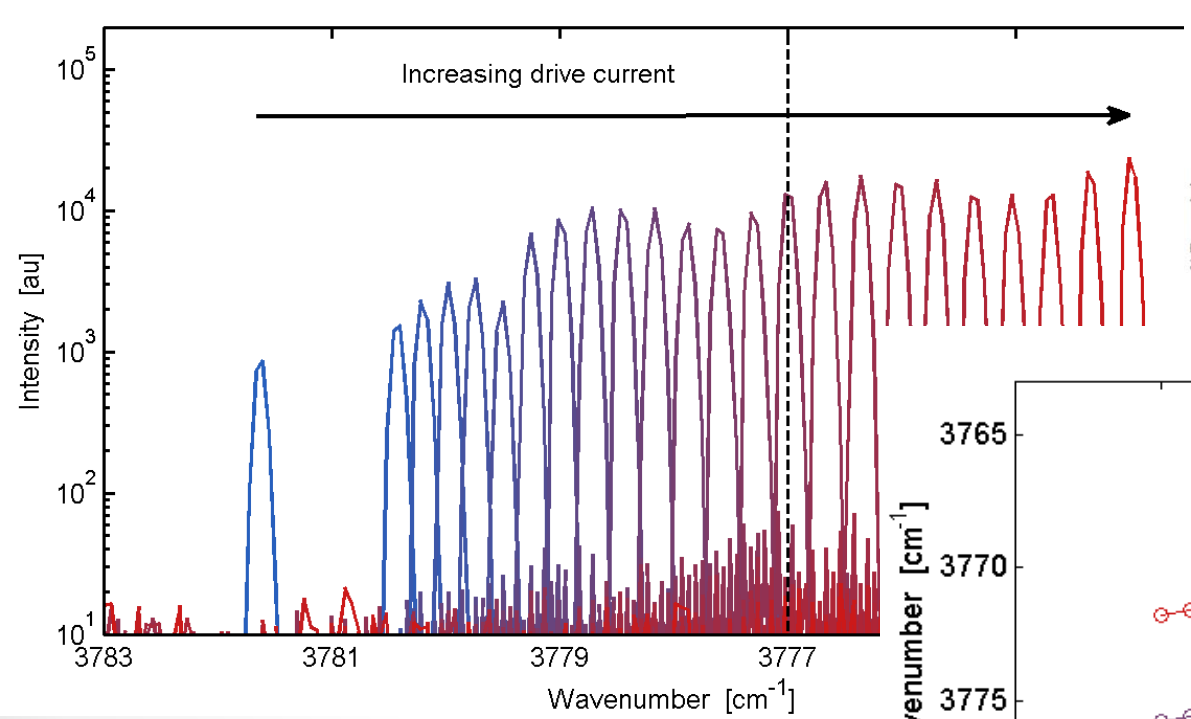
Power characteristics

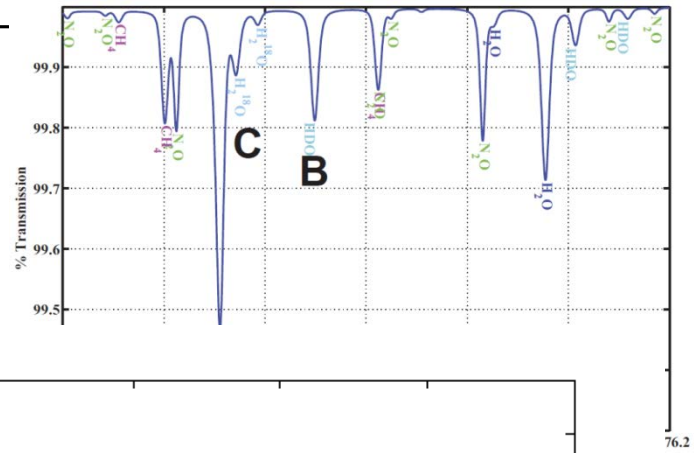
- Output power at 35 mW @ 10C, 600 mA.
- Still more than 20 mW @ 30C, 600 mA.
- No sign of thermal roll-over.
- Dips in LI curves are due to absorption of ambient water (feature, not a bug!).

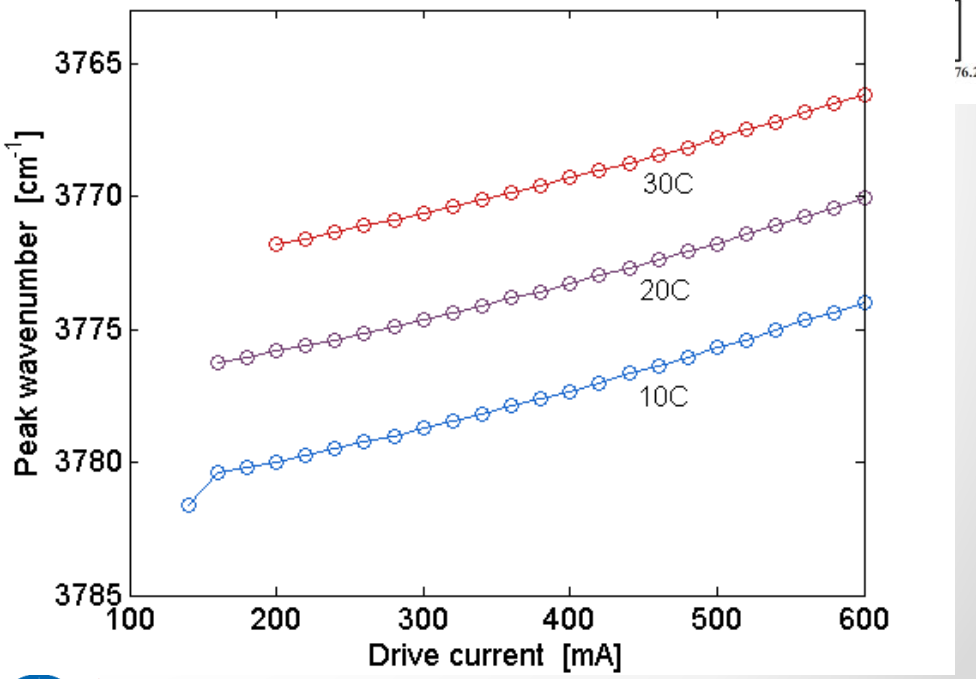


Spectral performance

Wavelength is tunable by temperature and/or drive current.

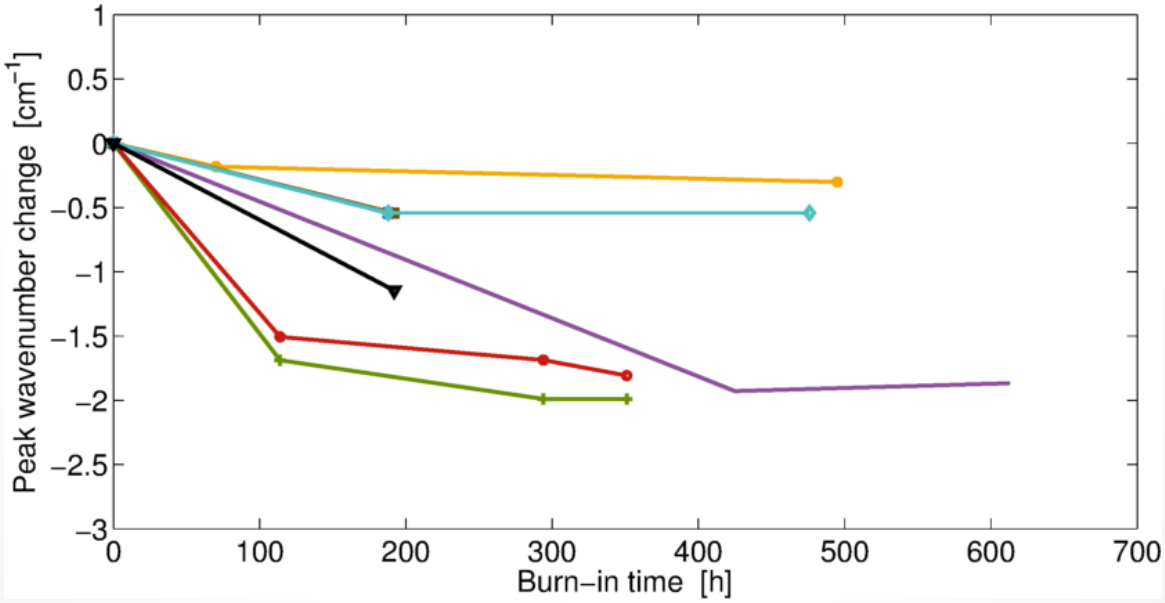






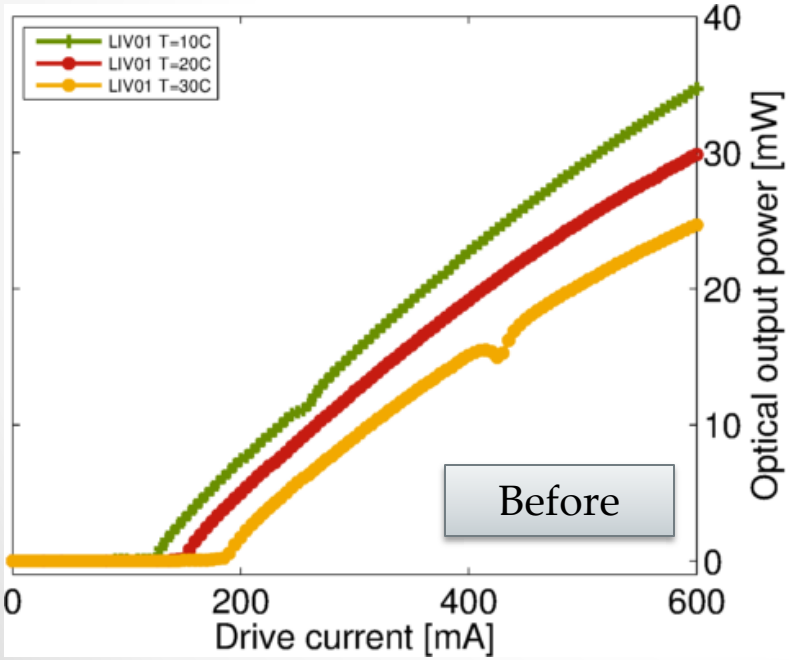
Reliability and life-time

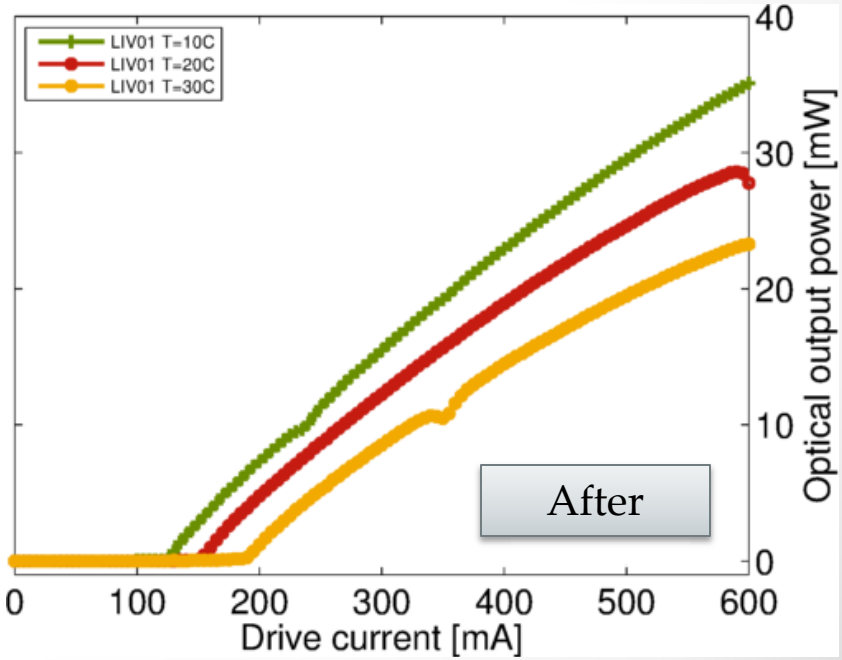
- Reliability and life-time test: devices submitted to elevated drive currents and mount temperatures.
- Over 3000 hours of accumulated testing has been performed, without a single failure.
- Peak wavenumber stabilizes after 100-200 hours. The change in peak wavenumber is less than 2 cm^{-1}. The output power is not reduced.



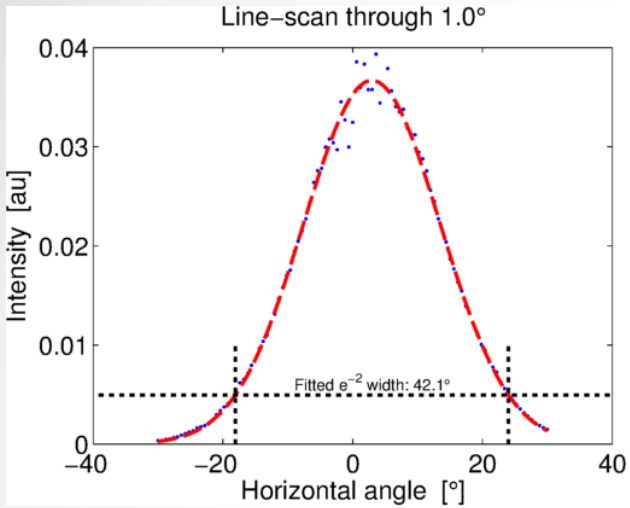
Packaging

- Lasers integrated into TO-3 packages.
- No significant degradation in performance noticed after packaging.

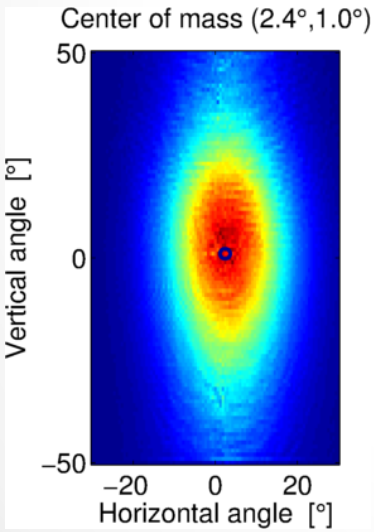


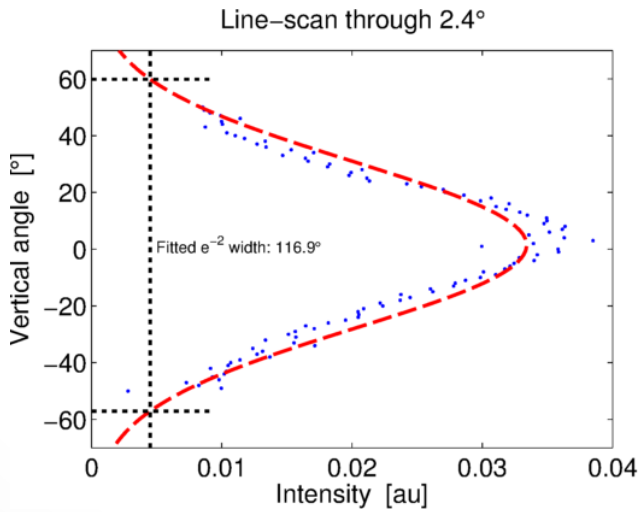


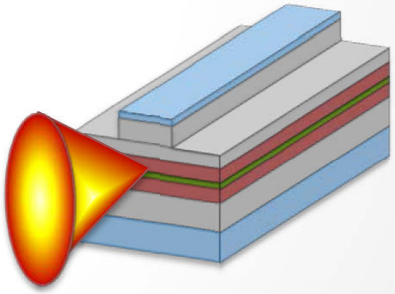
Shape of output beam



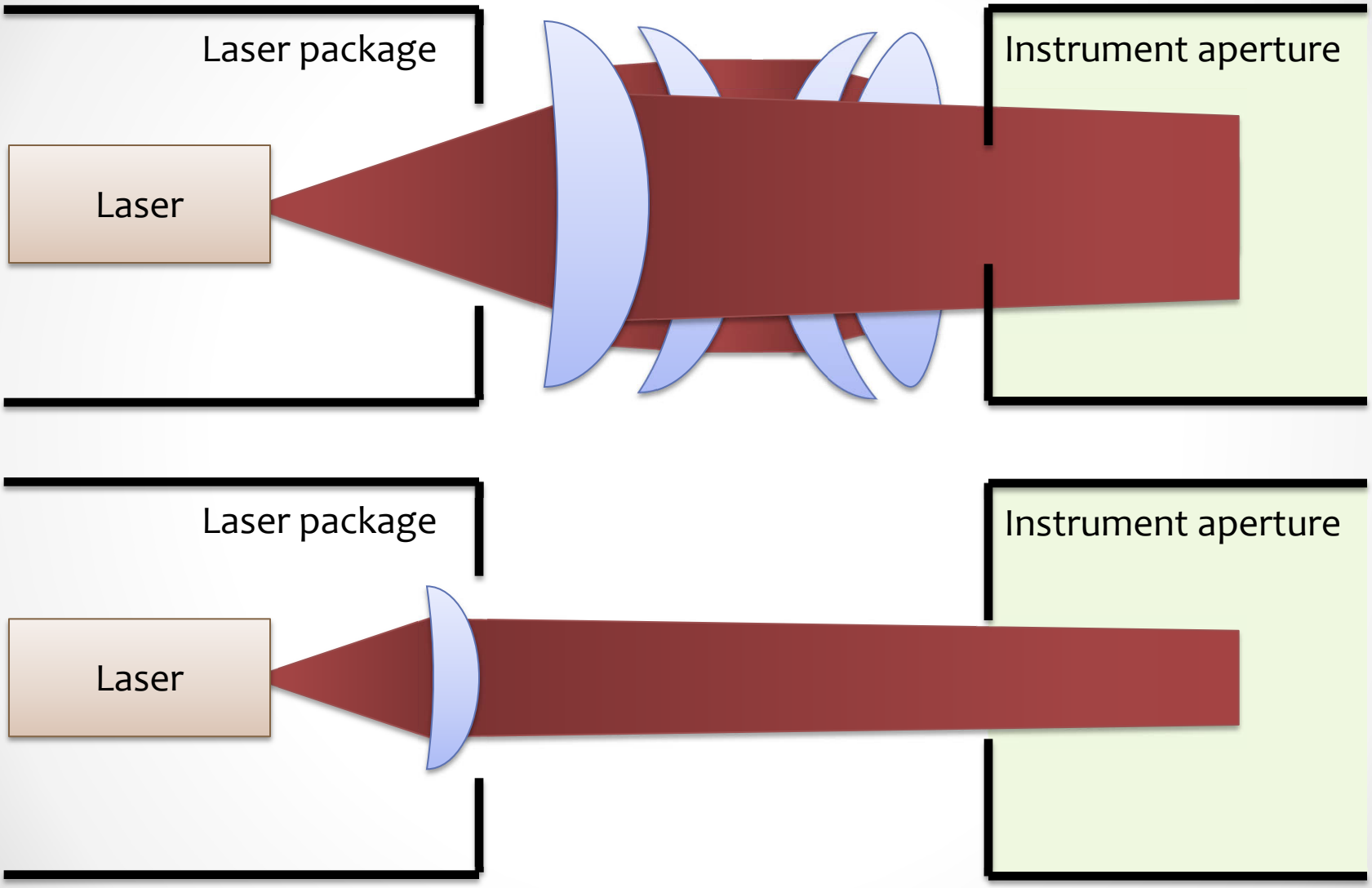
- Divergent and highly elliptical, normal for edge-emitters.
- Divergence angles: ~ 110 and 40 degrees.



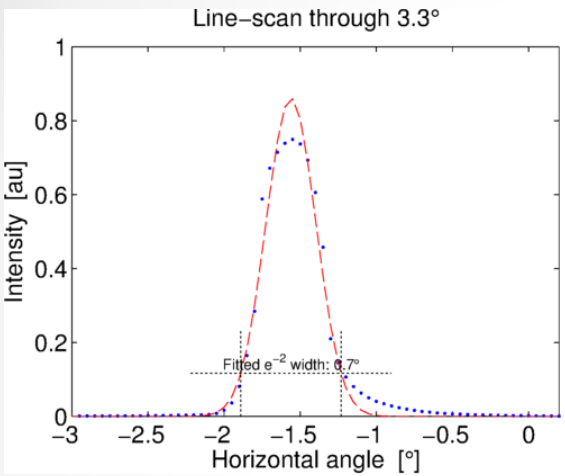


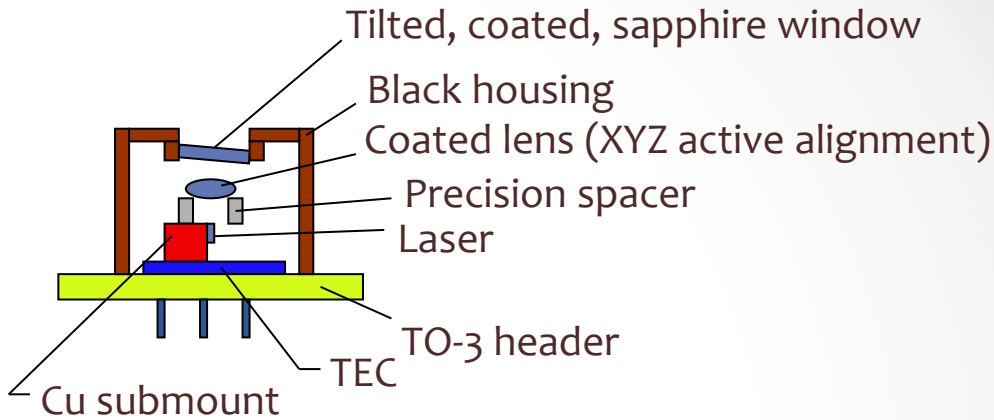


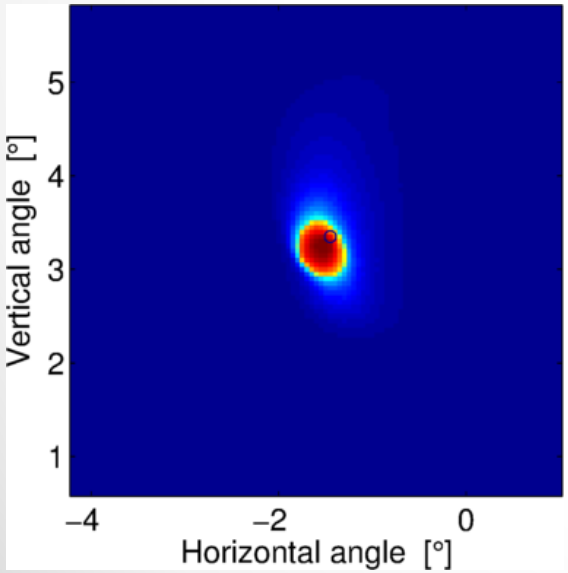
Collimating the beam

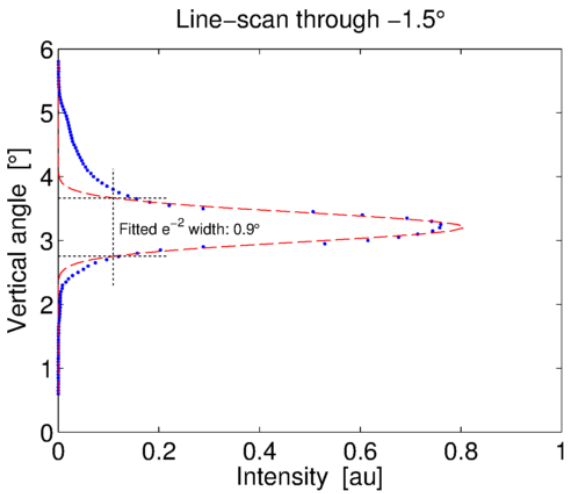


Package with internal lens









Next target: CH4

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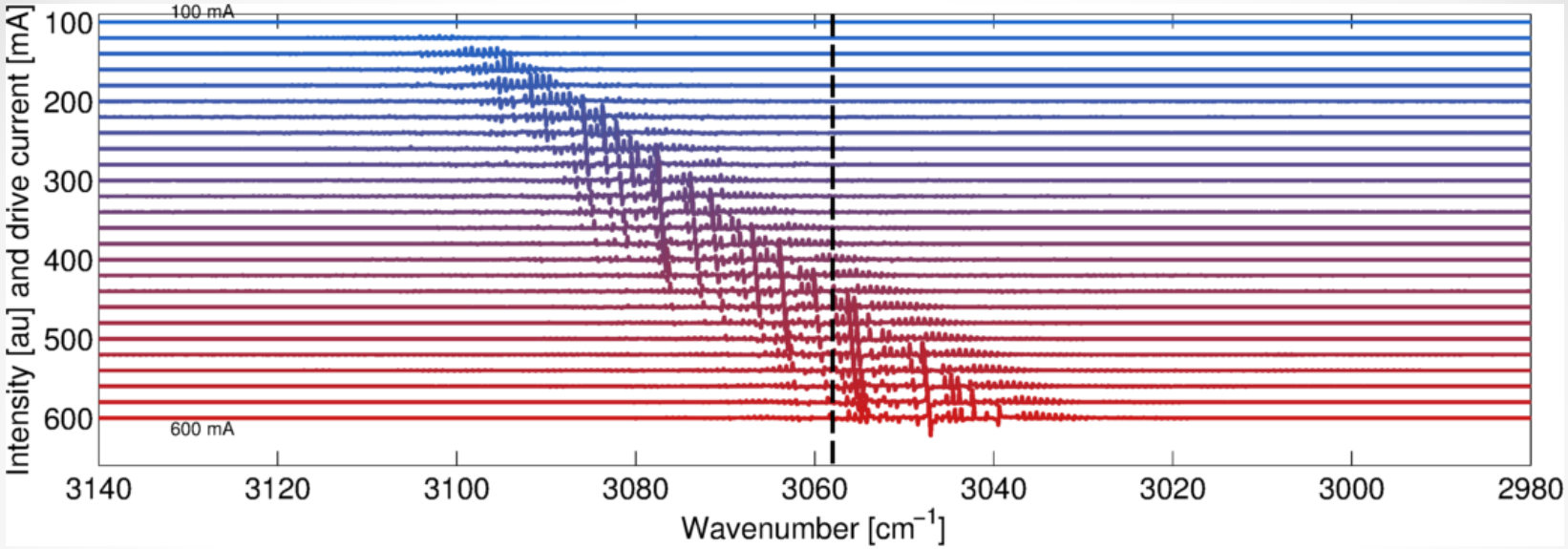
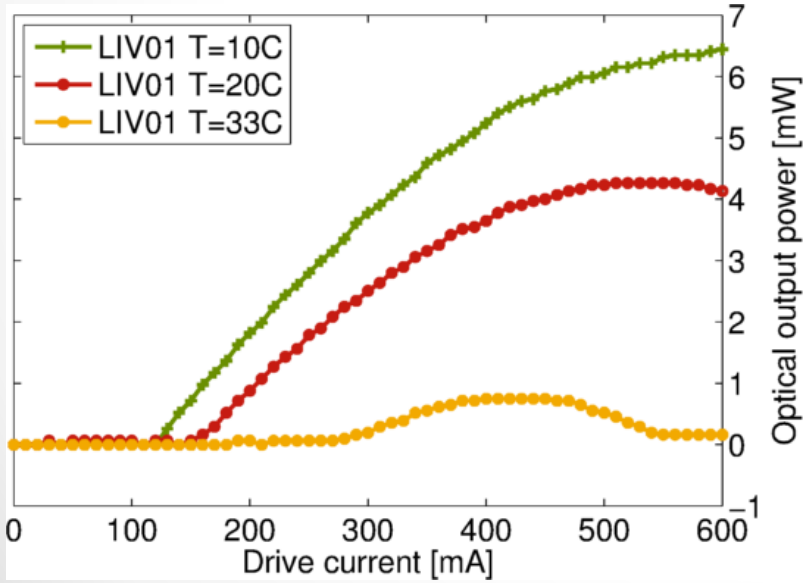
Initial results





- Hit target wavelength (3058 cm-1).
- Increase in output power (6 mW vs 1.5 mW)

Summary

- Successfully delivered 2 laser modules emitting more than 10 mW at 3777 cm-1 to Harvard for water detection.
- Developing laser package complete with collimating optics.
- Initial results show promising outlook for future methane detection missions like TLS.

Acknowledgements

Supervisor:

Siamak Forouhar

Colleagues:

Cliff Frez, Ryan Briggs, Mahmood Bagheri

Thanks for the attention!

High-power semiconductor lasers for in-situ sensing of atmospheric gases

Carl Borgentun, Microdevices laboratory (MDL)