Compact Diode Laser for Near Infrared Methane Spectroscopy

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Abstract

We are assembling a compact external cavity diode laser at 1.6 microns wavelength using the Littrow configuration. The wavelength of the laser will be tuned to resonance with the $2\nu_3$ transition near 1.63 μm in C-12 methane gas. The methane gas will be placed inside a hollow-core photonic crystal fiber, and used to develop optical frequency references. The diode laser will be coupled with an optical fiber to perform absorption spectroscopy. The diode laser is constructed with a 250 mW chip, in order to reach saturation of methane for sub-Doppler spectroscopy. We have adapted a compact, simple design from 780 nm to 1600 nm, and to higher power.

Motivation

This diode laser is needed for the development of methane references. In particular, extension of gas-filled hollow fiber references (first based on acetylene at 1.5 microns [1]) to longer wavelengths. We seek to demonstrate sub-Doppler spectroscopy in methane-filled hollow fibers at 1.6 microns. The diode laser is small, low in cost, and comprised of accessible commercial parts.

Compact Diode Laser

Existing diode laser design:

- Compact size (4x4x6.25 in), exterior made of aluminum, comprised of common, affordable commercial parts.
- Wavelength: 780 nm, Power: 100 mW.
- Uses a mirror to compensate beam motion (some translation of the beam results, but no change in direction).

Adapted diode laser design:

- Wavelength: 1600nm, Power 250 mW.
- Mount of diffraction grating significantly altered.
- Interlocking added. Electrical connections reconfigured for convenience and diode laser integrity.

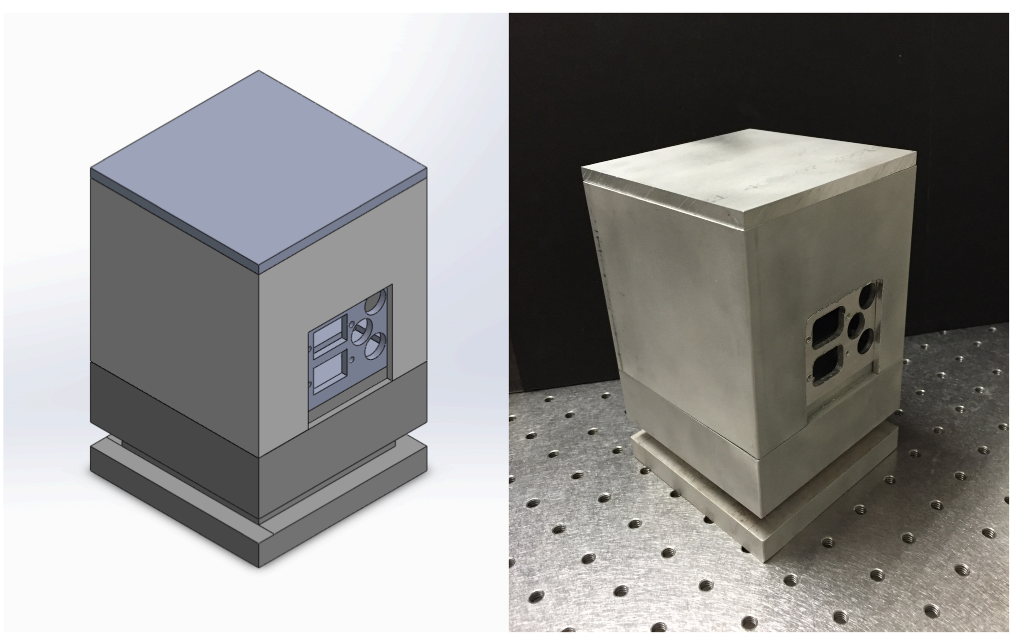

Figure 1: Adapted diode laser design (Left – Solidworks assembly of the the diode laser; Right – Milled assembly of the the diode laser)

- Diffraction grating:
  - Blaze angle: 28°41'
  - Blaze wavelength: 1.6 μm
  - 600 grooves/mm

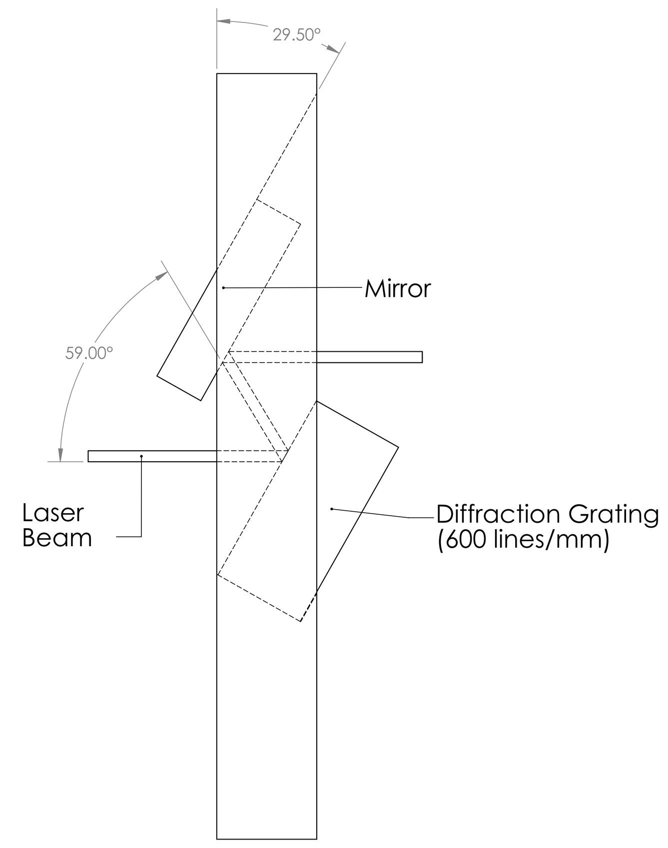

Figure 2: Using the Littrow configuration, the diffraction angle is calculated to be at 29.5°. The Littrow configuration determines an angle that makes the diffraction angle and incidence angle identical. The diffraction grating selects one wavelength to diffract back into the laser, narrowing the output and providing tunability.

Challenges:

- Interlocking the laser for safety purposes due to high power.
- Using the Littrow configuration to calculate the diffraction angle off the diffraction grating.
- Redesigning the grating and mirror mount to avoid beam clipping, passing a beam radius 4x the full width half maximum (FWHM).
- Reconstruction and machining of the adapted laser design at new grating angle.

Methane

- Tetrahedral molecule: CH_4
- Four vibrational modes: ν_1= 3025.5 cm^{-1}, ν_2= 1587.6 cm^{-1}, ν_3= 3158.6 cm^{-1}, ν_4= 1367.4 cm^{-1}
- Only vibrational modes ν_3 and ν_4 interact directly with infrared light where there is motion in both the carbon and hydrogen as a result of the dipole moment.
- In this research, we work with ν_3 as the $2\nu_3$ band is used to calculate the wavelength of transitions, which, in this case, is 1.6 microns.

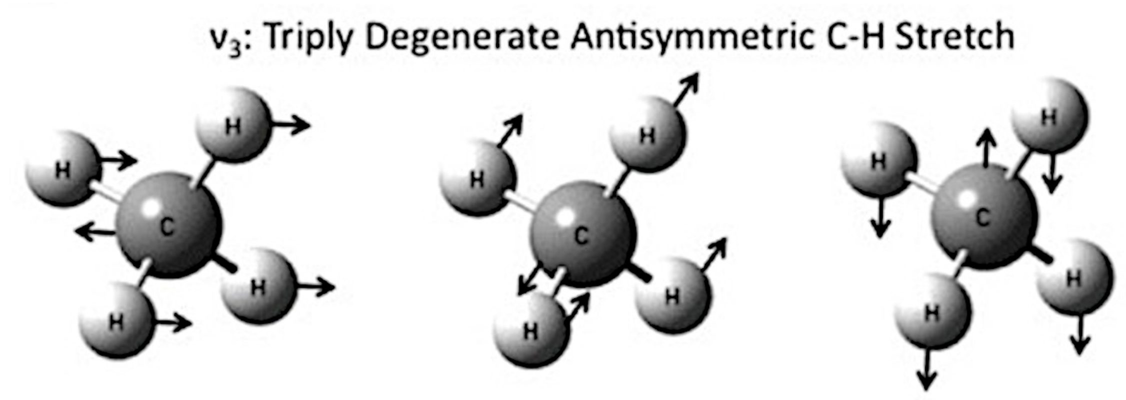

Figure 3: This is a depiction of the ν_3 vibrational mode of methane. This means that the motions of the carbon and hydrogen molecules are antiparallel to one another. Figure taken from Ref. [2].

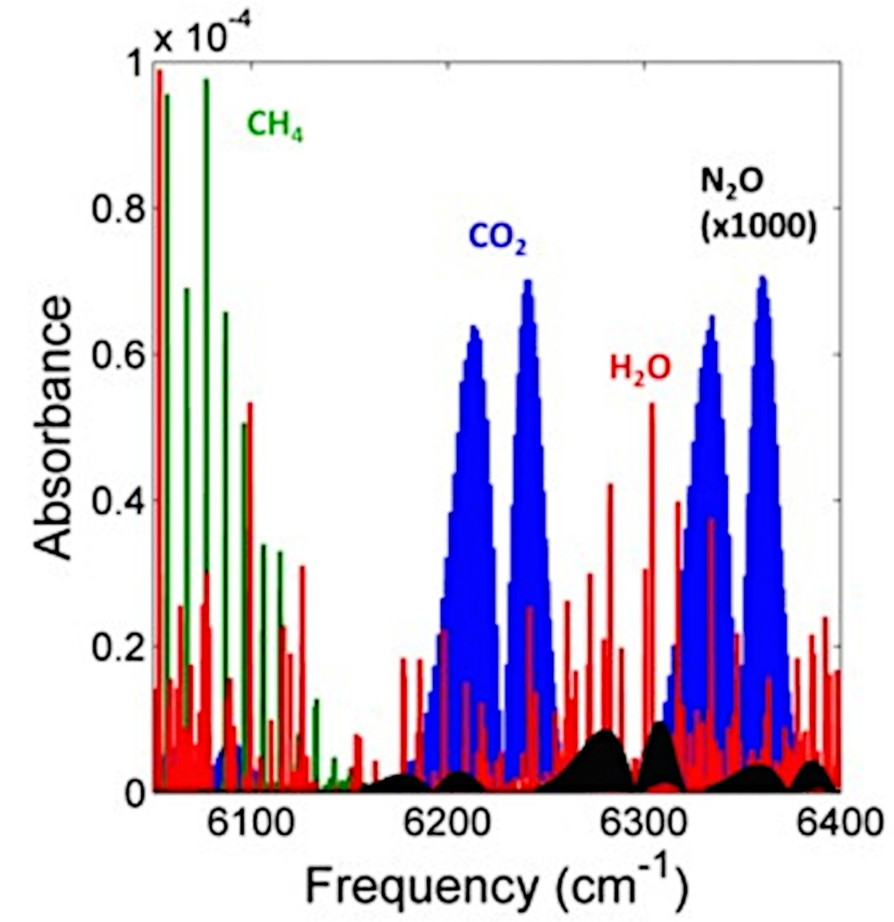

Figure 4: The green peaks display the atmospheric absorption of the methane spectrum in the $2\nu_3$ band in relation to the spectrums of other important atmospheric elements. Figure taken from Ref. [3].

Conclusion and Future Works

Assembling a 1.6 microns diode laser required understanding numerous concepts and sufficient preparation time. Such topics included rotational-vibrational spectroscopy, methane vibrational structure, Littrow configuration, Gaussian beam optics, laser diodes, and the sub-Doppler spectroscopy. All parts are purchased and machined, and the diode laser is nearly assembled. Next we will align the laser, fiber-couple the laser, fill a hollow core fiber with methane, and tune the laser to the resonance of the methane line. The diode laser, coupled to an optical fiber, will be used for absorption spectroscopy and sub-Doppler spectroscopy. This research is looking towards producing a portable frequency reference at 1.6 microns through sub-Doppler spectroscopy. This will ultimately lead to sealed hollow-core fibers filled with methane absorbing laser light as a frequency reference.

References:

[1] C. Wang *et al.,* "Acetylene frequency references in gas-filled hollow optical fiber and photonic microcells" Appl. Opt. 52, 5430-5439 (2013).

[2] Methane vibrational normal modes [Online image]. (n.d.). Received August 1, 2016 from https://www.researchgate.net/figure/278652214_fig4_Figure-18-18-Methane-vibrational-normal-modes

[3] DIAL system [Online image]. (n.d.). Received August 1, 2016 from http://www.nist.gov/pml/electromagnetics/grp05/other-activities.cfm

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