HOLLOW WAVEGUIDE CAVITY RINGDOWN LASER ABSORPTION SPECTROSCOPY PROGRESS FOR TRACE GAS DETECTION. Christopher. B. Dreyer[1] and Greg S. Mungas[2], [1]Colorado School of Mines, Center for Space Resources, Golden, CO 80401, cdreyer@mines.edu, [2] Jet Propulsion Laboratory, California Institute of Technology (M/S 306-336 4800 Oak Grove Dr., Pasadena, California 91109).

Introduction: Cavity Ringdown [1,2] Laser Absorption Spectroscopy (CRDS) is capable of providing extremely sensitive measurements of gas species. We are developing the concept of incorporating pulsed CRDS into a hollow-waveguide (HWG-CRDS) both for reducing the sample volume as well as enhancing the signal-to-noise ratio (SNR) by up to $\sim10^4$ by injecting light into the HWG cavity through a small aperture in one of the cell mirrors [3]. For low power instrument applications (i.e. planetary science), the enhancement in SNR results in a potential $\sim10^4$ reduction in laser power for a comparable CRDS terrestrial laboratory measurement at one extreme, or a potential $\sim10^8$ improvement in CRDS temporal resolution through reduced sample averaging with a fixed low-power laser source.

HWP-CRDS: In CRDS an optical cell is formed by highly reflective mirrors and charged with a laser. The rate of energy decay in the cavity is monitored and related to the number density of absorbers in the cell. In conventional pulsed CRDS, light is injected into the cavity through a highly reflective mirror (R = 99.9%-99.99% typical); hence most of the laser photons are not transmitted into the cavity. In the HWP-CRDS concept the cavity is formed by mirrors and a hollow waveguide. A simplified HWP-CRDS experimental arrangement is shown in Figure 1. The laser enters the cavity through an aperature (<50 µm diameter) in the reflective coating of mirror R1. The energy in the cavity is substantally increased relative to conventional CRDS with end mirrors if losses in the HWG are low. The HWG constrains the light propagation to travel the axial length of the waveguide. Light injection through the aperture populates modal fields in the waveguide that propagate in the waveguide and ringdown between the two cavity mirrors.

In addition, by incorporating the waveguide as the gas cell, one can simultaneously contain the light beam as well as constrain the size of the gas sample. Conventional absorption spectroscopy using a Herriot cell of 20cm length and 2.5 cm mirror diameter would require a gas sample of 98 cm^3 [4]. A conventional CRDS cell of the same length would be smaller because the mirror size can be reduced as the beam is aligned to trace back and forth over the same path; for 1 cm diameter mirrors the volume would be 24 cm^3. We estimate that with HWP-CRDS, and a HWG designed for the 3.3 µm CH_4 band, the HWG diameter can be 3 mm, hence the gas volume required is reduced to 2.1 cm^3. Reduction in required instrument gas volume reduces requirements on aquired sample volume and mass.

HWP-CRDS Progress: We have developed detailed models to describe the anticipated performance of an HWP-CRDS instrument. Theory of waveguide modes and propagation characteristics (i.e. propagation angle, linear attenuation, modal velocity) inside a Bragg hollow waveguide is summarized in [3]. Loss mechanisms in the waveguide are radial transmission through the "leaky" waveguide, absorption losses in the cladding and gas core, and loss at the interface between the HWG and the mirrors. The Bragg HWG model predicts the first two losses mechanisms. Absorption losses manifest themselves through the complex component of indices of refraction for cladding materials and the gas core. For the case of a gas-filled core, the imaginary component of index of refraction becomes a function of the volume fraction of absorbers.

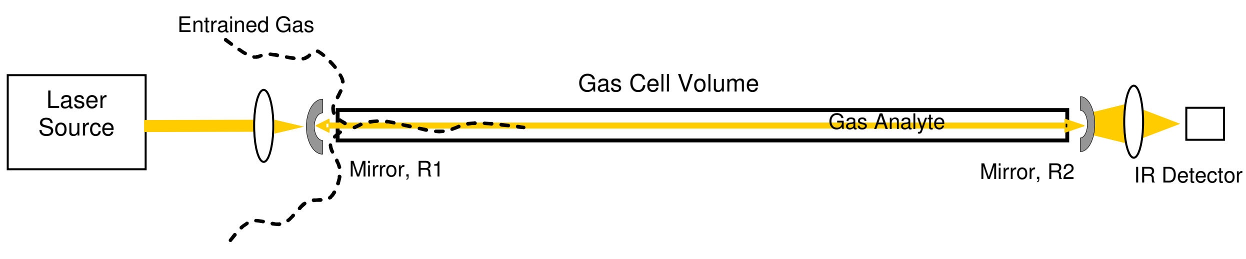

Figure 1: Schematic of HWP-CRDS.

A HWG for use at 1.66 µm has been designed and manufactured. The 1.66 µm HWG will allow measurements of CH_4 absorption. Figure 2 shows an image of the HWP-CRDS 1.66 µm CH_4 experiment.

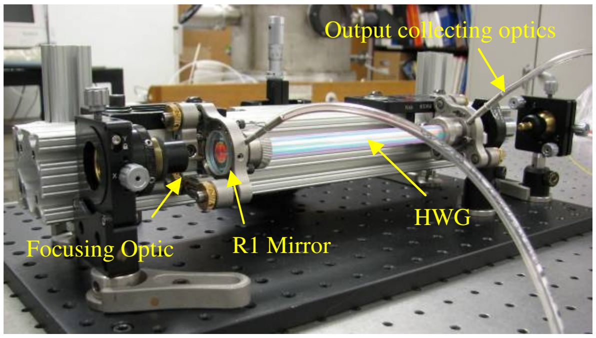

Figure 2: HWP-CRDS 1.66 µm CH_4 experiment.

Figure 3 shows a comparison of waveguide linear attenuation characteristics at 1.6429 µm to experimental results at two modal propagation angles. To minimize attenuation in the HWG the propagation angle of injected light is kept low, <5°. TE and TM modes trace slightly different attenuation with propagation angle as seen by the two sets of model data points of set by about $1x10^{-2}$ dB/m. As the modal propagation angle is decreased the calculation becomes increasing difficult, hence no calculations were made below 0.75 degrees.

The experimental results were derived by measurement of ringdown time with and without the waveguide at approximately 1.6409 µm. Attenuation of the cell due only to the mirrors was determined from measurements of ringdown time without the waveguide and with the laser entering the cavity unfocused. The unfocused laser propagates with the far field divergence of the Sacher Laser Lion Littman laser of approximately 1.5 mrad. The low propagation angle HWG attenuation was determined by ringdown measurements with the laser entering unfocused and the HWG in place. Measurements of ringdown time at propagation angle of 1.5 degrees were made by focusing with a 75 mm focal length lens. The gap between the HWG and mirrors was approximately 1 mm at each end. The error bars shown were derived from confidence intervals on several ringdown time curve fits.

Conclusions: Agreement between measurement and model is good. The experimental results fall below the model results. This may be due to absorption in the cladding material being less than the value used in the model, that is, lower complex index of refraction. Calculations were performed with worst case cladding absorption. The results are promising for successful implementation of the HWP-CRDS concept.

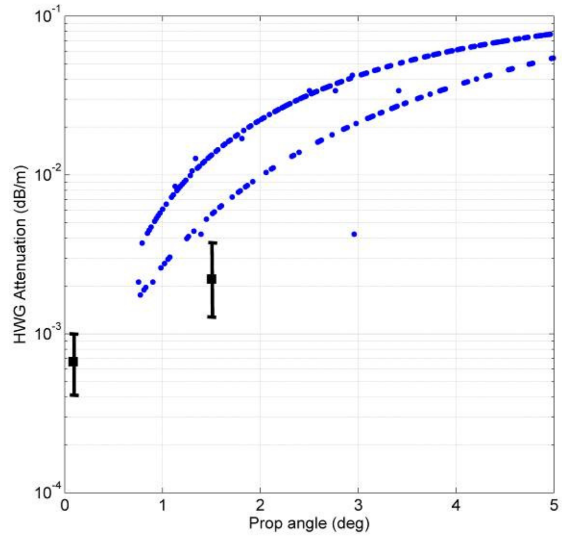

Figure 3 - Empty Bragg HWG Modes and Attenuation (at λ_j = 1.6429 micron) vs. propagation angle. Blue circles: model. Black squares: measurement.

Aknowledgements: This work is supported under NASA grant # NNG04GN40G, ASTID, Dr. Michael New, Science Mission Directorate, Chris Dreyer PI, Colorado School of Mines, Greg Mungas IPI, Jet Propulsion Laboratory.

References: [1] A. O'Keefe, J.J. Scherer, J. B. Paul, R. J. Saykally, in *Cavity-Ringdown Spectroscopy, an Ultratrace-Absorption Measurement Technique,* ACS Symposium Series Vol. 720, K.W. Busch and M.A. Busch, Editors, American Chemical Society, Washington, DC (1999). [2] B. A. Paldus and R. N. Zare, in *Cavity-Ringdown Spectroscopy, an Ultra-trace-Absorption Measurement Technique,* ACS Symposium Series Vol. 720, K.W. Busch and M.A. Busch, Editors, American Chemical Society, Washington, DC (1999). [3] G. S. Mungas and C. B. Dreyer, (2006) IEEEAC#1476. [4] C. R. Webster, (2005) Appl. Opt., 44, 1226-1235.