DEVELOPMENT PROGRESS OF PULSED CAVITY RINGDOWN LASER ABSORPTION SPECTROSCOPY IN A HOLLOW WAVEGUIDE FOR TRACE GAS DETECTION.

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Introduction: Cavity Ringdown [1,2] Laser Absorption Spectroscopy (CRDS) is capable of providing extremely sensitive measurements of gas species. Previously, we presented 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 ~10^4 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 ~10^4 reduction in laser power for a comparable CRDS terrestrial laboratory measurement at one extreme, or a potential ~10^8 improvement in CRDS temporal resolution through reduced sample averaging with a fixed low-power laser source. We present progess on a HWG-CRDS experiment on the 1.66 μm methane absorption band.

HWP-CRDS: In CRDS an optical cell is formed by two or more 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 the back of a highly reflective mirror (R = 99.9%-99.99% typical); hence most of the laser photons are not transmitted into the cavity. The concept of HWP-CRDS is that the cavity is formed by the mirrors and a hollow waveguide. A simplified HWG-CRDS experimental arrangement is shown in Figure 1. The laser is injected into the cavity through an aperature (<50 μm diameter) in the reflective coating of mirror R1. The energy in the cavity is substaintally increased relative to conventional CRDS with end mirrors only if losses in the HWG can be kept low. The HWG constrains the light propagation to travel the axial length of the waveguide. Light injection through the aperture excites modal fields in the waveguide that subsequently 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 likely be smaller because the mirror size can be reduced as the beam is aligned to trace back and forth over same path; for 1 cm diameter mirrors the volume would be 24 cm^3. We estimate that with HWP-CRDS, and the HWG designed for the 3.3 μm CH_4 band, the HWG diameter can be 3 mm, hence the gas volume required is 2.1 cm^3. Reduction in required instrument gas volume implicitly reduces aquired sample volume and mass.

HWP-CRDS Progress: We have developed detailed models to describe the anticipated performance of an HWP-CRDS instrument. The theory behind determining the waveguide modes and propagation characteristics (i.e. propagation angle, linear attenuation, modal velocity) inside a Bragg hollow waveguide is summarized in [3]. Two fundamental energy dissipative losses exist in the waveguide: 1) Radial transmission through the "leaky" waveguide, and 2) Absorption losses in the cladding and gas core. Both losses are accounted for in the model. Absorption losses manifest themselves through the complex component of indices of refraction, ni_x, for cladding materials and the gas core. For the special case of a gas-filled core, the imaginary component of index of refraction becomes a function of the volume fraction of absorbers.

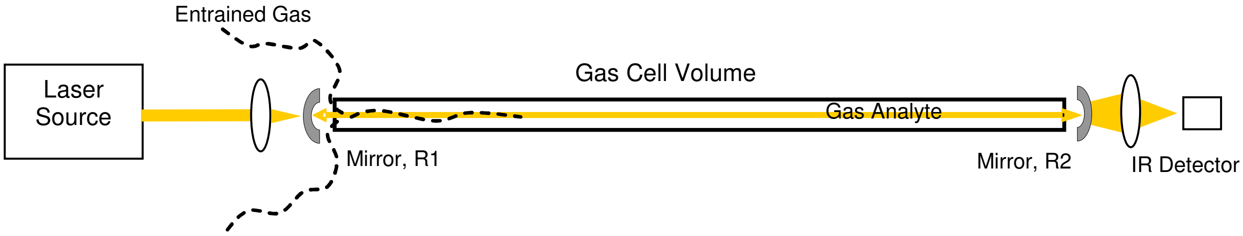

Figure 1: Schematic of HWP-CRDS.

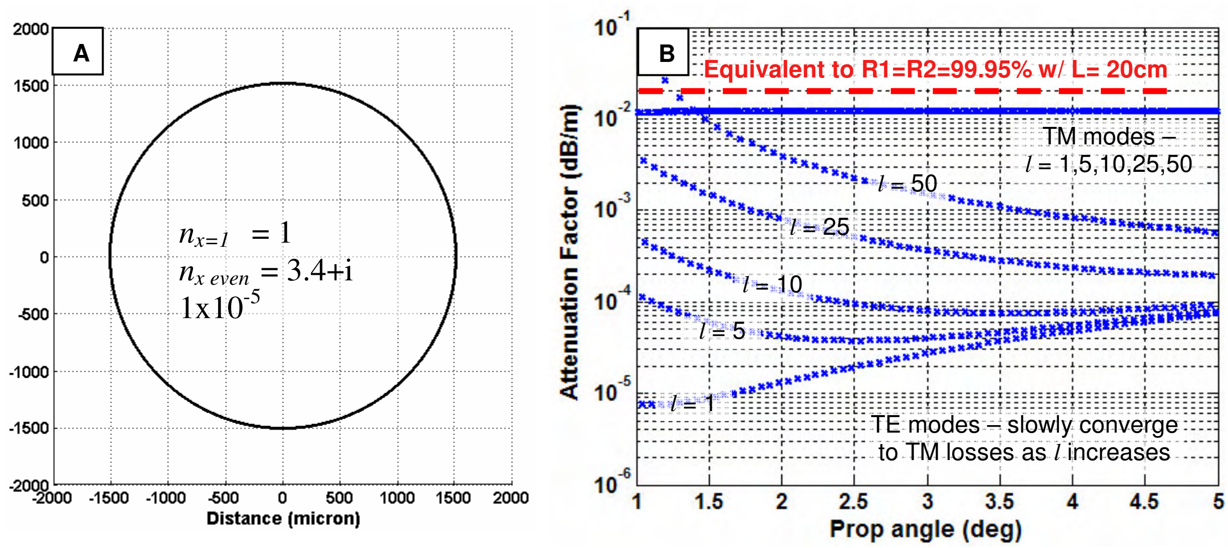

Figure 2 - Empty Bragg HWG Modes and Attenuation (at λ_j = 3.27micron) vs. propagation angle and *l*, modal index. A) Bragg HWG Geometry; B) Bragg HWG Attenuation Compared to CRDS Equivalent Mirror Loss over 1 Roundtrip for a 20cm cavity.

Figure 2 illustrates an example of linear attenuation characteristics in a waveguide vs. equivalent linear losses associated with CRDS mirrors during a pulse roundtrip. To minimize attenuation in the HWG the propagation angle of injected light is kept low, <5°. As the light becomes progressively more multimodal (*l* increases) the TE mode losses approach the TM mode loss, but all remain below the loss equivalent to two additional high reflectivity mirrors in the CRDS cell.

Procurement of a HWG for use at 1.66 µm, of our own design, has been completed. The 1.66 µm band was chosen because technical expertise for producting high reflectivity thin film dielectric coatings in the NIR is more developed than the mid-IR above 3 µm. The 1.66 µm HWG will allow measurements of CH_4 absorption. Figure 3 shows an imge of the HWP-CRDS 1.66 µm CH_4 experiment in development.

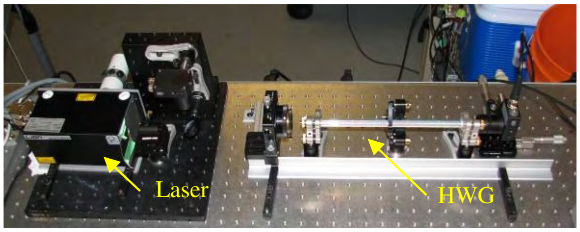

Figure 3: HWP-CRDS 1.66 µm CH_4 experiment in development.

Conclusions: HWP-CRDS, hollow waveguide pulsed cavity ringdown laser spectroscopy (HWP-CRDS), offers the possibility of: 1) Enhanced minimum gas detection limits, 2) Small analyte sample volumes, 3) A miniaturized, instrument implementation with no precision moving parts, and 4) Rapid measurement times (~10µs minimum measurement at a particular wavelength. A total absorption background scan is limited by the tuning rate of the laser and the number of co-additions).

We have developed detailed models to describe the anticipated performance of an HWP-CRDS instrument, and have performed a comparative study with existing techniques. We have procured a HWG for 1.66 µm that will be used for experimental verification of the HWP-CRDS concept and detection of CH_4 at trace levels.

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