Development of sensors using evanescent wave interactions in sapphire optical fibers

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Objective

The goal of this project is to test the feasibility of using bare sapphire fibers for sensing gas species in coal combustors. The novel approach is to use evanescent wave interaction between laser transmission through the fiber and gas flow over the fiber. During this 1-year project, bare fibers will be tested in laboratory gas cells and laboratory scale combustors. The durability of the bare fibers will be tested for lifetimes at flame temperatures, and coatings for the bare fiber will be explored to either enhance durability or add functionality.

Accomplishments to Date

During the 3-months that this project has been funded, experimental equipment for testing evanescent interaction in bare sapphire has been constructed and initial tests have been made. The apparatus is shown in Fig. 1. Laser light from a telecommunications diode laser is coupled into a silica fiber and split using a 2x2 fiber splitter. Half of the laser transmission is passed through an absorption test cell and measured using a photodiode. The other half is measured without transmission through the gas cell using a reference photodiode. The installed laser was selected so that its wavelength is resonant with vibrational transitions in CO_2. Two test cells were fabricated. The first test cell consists of a hollow optically accessible cylinder with no sapphire fiber. This test cylinder allows for standard absorption measurements as a baseline signal. This test chamber has been used to validate simulations of expected CO_2 absorption. Figure 2 shows a sample measurement of CO_2 as the wavelength of the laser is scanned across three separate absorption lines. This scan is performed by varying the current supplied to the laser and can be performed at repetition rates around 1 kHz. The figure shows a ratio of measured laser transmission when the cell is filled with nitrogen (not resonant with the laser) and when the cell is filled with carbon dioxide. Peak laser absorption is around 10% in this direct absorption mode. The wavelength of the laser was separately calibrated.

A second test chamber was created similar to the first; however, a single crystal sapphire optical fiber was placed within the cell. The fiber was connected to the end wall of the cell using SMA fiber connectors and the output of the laser was passed into the sapphire fiber. Good transmission through the sapphire fiber was observed. As the laser transmission is guided through the sapphire fibers, total internal reflection occurs at the sapphire/gas interface (normally a core/cladding interface in standard fiber). The electro-magnetic field of the laser transmission extends into the gas for a distance on the order of the laser wavelength (~1.6 μm); however most of the field remains in the fiber. It is expected that absorption via evanescent interaction between the laser and gas will be several orders of magnitude weaker than direct absorption (as in Fig. 2). Because of its weakness, advanced approaches to observing the absorption signal are being tested. One method of improving sensitivity is to modulate the laser wavelength and observe harmonics of the modulation in the absorption signal. An example of this harmonic detection is shown in Fig. 3, where 2nd harmonic detection of CO_2 in direct absorption (the first test cell without the sapphire fiber) has been completed. In this case, a 100 kHz small amplitude sine wave oscillation is added to the current provided to the laser diode. As the laser wavelength is slowly (~1 kHz) varied across the three CO_2 absorption features, smaller oscillations in wavelength occur. The signal at the photodiode includes this oscillation; however, since the absorption profiles are not linear, harmonics of the oscillation also are measurable. These were detected using a lock-in-amplifier set to detect 2nd harmonic signals and this measurement is shown in Fig. 3. The 2nd harmonic measures the derivative of the absorption profile and is consistent with the direct absorption profile from Fig. 2.

Finally, 2nd harmonic detection of CO2 in the sapphire fiber using evanescent interaction has recently been tested and is shown in Fig. 4. The measurement does not show a characteristics CO2 shape due to interferences from etalon effects in the system. In the connection between the silica fiber and the sapphire fiber, some reflection could not be removed and these reflections contribute to an oscillating interference background. Current efforts to remove this etalon interference include shaping the fiber end for less reflection. These etalon interferences are not uncommon in diode laser absorption studies, and we have addressed them in previous research.

Future Work

To improve upon the current measurements, the location and cause of etalon interferences are being systematically reduced and unique methods for coupling between the silica fiber from the laser and the sapphire fiber are being explored. Bare plastic fiber is also being used in low-temperature measurements where no index of refraction mismatch occurs between the laser and test fiber, thereby limiting the reflections that lead to etalon effects. These fibers will be used for baseline tests of the evanescence approach. Larger diameter sapphire rods have also been acquired and are being tested for evanescent interactions. These 2-mm rods can be manipulated more easily that the 250 μm fiber allowing for faster testing of novel beam transmission approaches.

Following these initial experiments to characterize the strength of the evanescence signal in the sapphire fiber, durability tests of the fiber will be conducted by testing for changes in laser transmission as the fibers are subjected to high temperatures for extended periods of time. We have currently explored several coating materials and approaches for modifying the structural and optical properties of the fiber surface and will shortly begin coating fiber samples to test modification to the laser transmission properties under high temperature conditions.

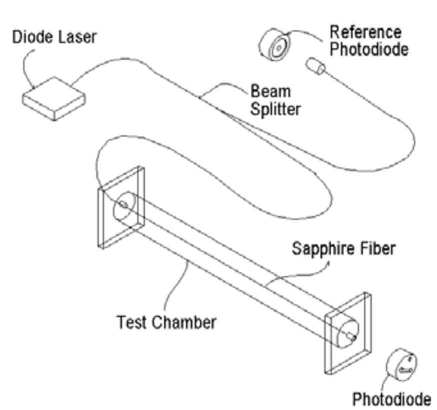

Figure 1: Experimental setup

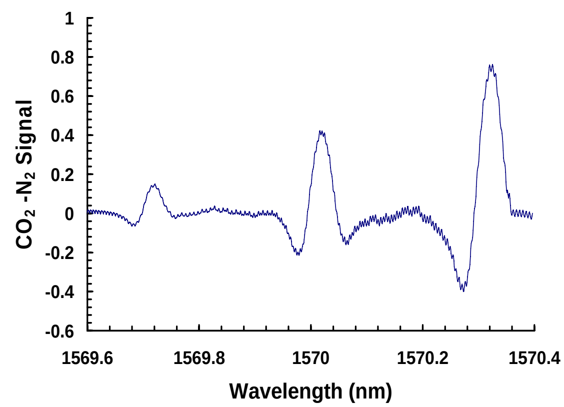

Figure 3: 2nd harmonic absorption without fiber

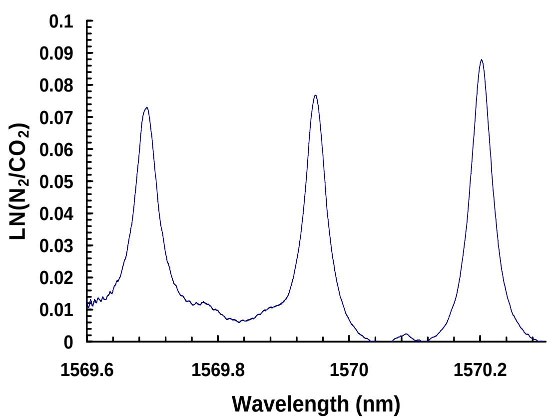

Figure 2: CO_2 absorption without fiber

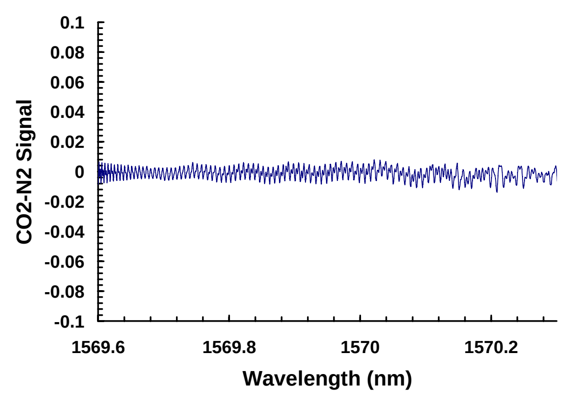

Figure 4: Second harmonic CO_2 absorption with fiber

List of Papers, Presentations and Student Support

Thus grant began January 2006. No papers have been submitted to date.

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