Development of a Miniature Faraday Modulation Spectroscopy System for Monitoring of Nitric Oxide in Combustion Processes.

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Faraday Modulation Spectroscopy (FMS) can provide ultra high sensitivity and specificity to paramagnetic molecular species without need for multipass- or high finesse cavities usually required for detection limit enhancement. Nitric oxide (NO) detection in the one parts-per-billion range was recently demonstrated with a FMS system employing 44cm single-pass optical path [1]. This system was based on table-top measurement instrumentation, and thus has limited applications in the field. We are developing a system with sensitivity to NO that is required by combustion diagnostics applications (e.g. in automotive industry) in the range of one parts-per-million, but at the same time is much smaller and lightweight. In this project we investigate two aspects of the FMS technology: Development of a prototype miniaturized sensor module, and development of LabVIEW-based data acquisition and processing technology.

The miniature sensor uses a Quantum Cascade Laser (QCL) as the light source, as shown below in Figure 1. The light is directed through a Rochon prism and passes through a 2 cm-long gas cell, which is placed in an axial magnetic field modulated at frequency *f*. A polarization rotator based on two metallic mirrors is placed at the end of the cell, allowing arbitrary rotation of the polarization of the returning beam, in our case nearly 90 degrees. The configuration of the mirrors is such that the optical axis of the returning beam is parallel and shifted with respect to the optical axis of the incident beam. The presence of paramagnetic NO in the cell causes rotation of the polarization of the laser light, allowing us to sense the concentration of the target gas. The beam passes back through the magnetic cell and the polarizer. This allows the same Rochon prism to act also as an analyzer. The intensity of the light that passes through the polarizer is measured with a photodetector and demodulated using phase sensitive detection with a lock in amplifier (LIA), which yields the concentration of the target species. A 3D model of the prototype device is shown in Figure 2.

The sensitivity of this method strongly relies on the LIAs that are used to measure the small photodetector signals strongly buried in noise e.g. due to ambient radiation, stray signals, etc. Hardware LIAs work well, but they are large and heavy therefore software based LIA-algorithms offer an excellent alternative [2]. We have developed a LabVIEW-based LIA to provide sensitive data acquisition and processing, together with an integrated computer-based control of the entire sensor system. Our lock-in produces a 1 KHz signal for modulation of the magnetic cell. This signal is also used as the reference for recovering the signal from the detector. The LIA uses digital signal processing algorithms to multiply the signal with the reference and yield a value corresponding to the amplitude and phase of the measured signal. The algorithm we have developed has been able to recover 1mV signals from 5 V of ambient white noise, corresponding to a 76-dB dynamic range. The next phase of the project will be concerned with integration of the developed technologies and performance tests of a complete system.

References:

1. Lewicki, et al. “Ultra-sensitive detection of Nitric Oxide at 5.33 um using External Cavity QCL-based FRS Spectroscopic sensor platform” Conference on Lasers and Electro-optics, *CLEO 2008* (2008).
2. Masciotti, et al. “Digital Lock-in Detection for Discriminating Multiple Frequencies” *IEEE Transactions on Instrumentation and Measurement,* **Vol 57,** Pg. 182-189 (2008).

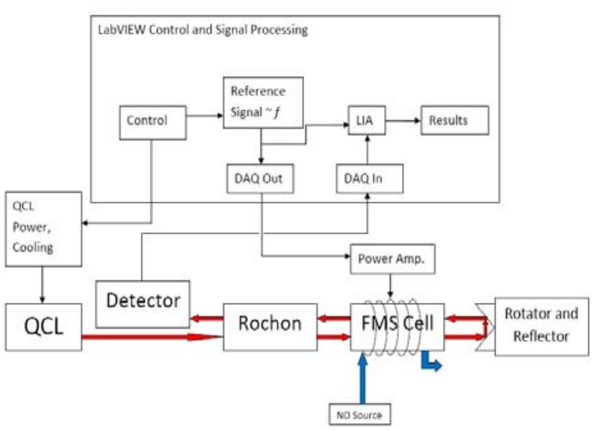

Figure 1: Reflective FMS system

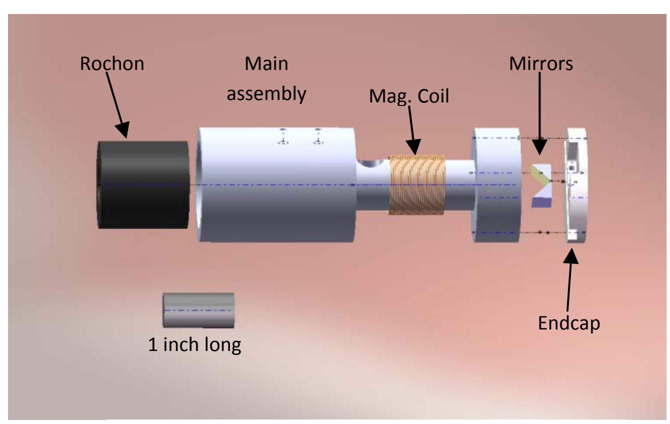

Figure 2: Prototype sensor, including Rochon prism, magnetic coil, mirrors, and endcap. The small bar is 1 inch long.