Serge Minin &
Rahul Gladwin
ECE 371GS
7/8/2003

Observation of CO and CO_2 Absorption Lines at 1.57 µm

ECE 371GS Final Project Report

Purpose

In this project, we detected the absorption lines of CO_2 gas near the 1.57 µm (range. We used a tunable diode laser to emit the desired wavelength range. Our nominal path in CO_2 ranged from 5 cm to 100 cm.

Differential Absorption

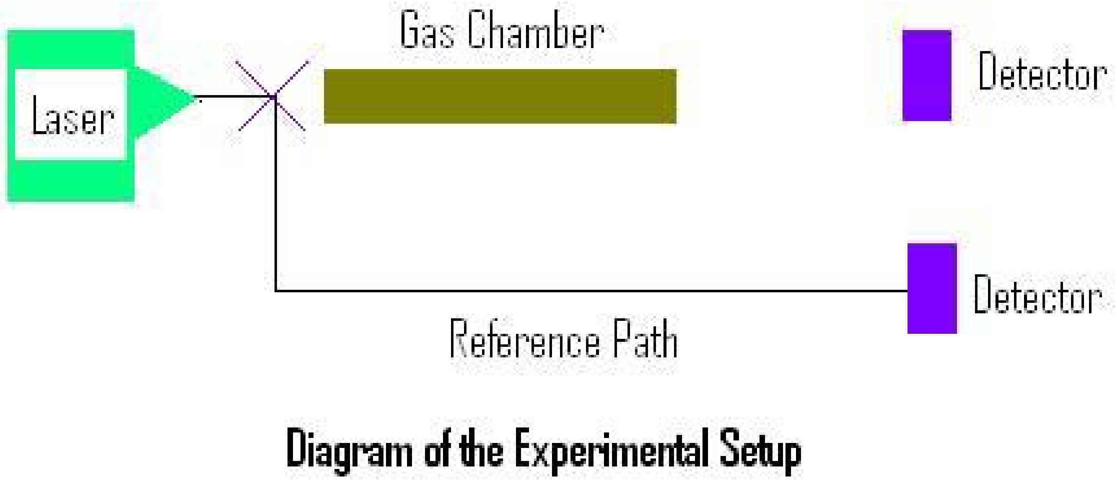

Figure 1. Generic differential absorption setup.

In the above diagram, the light is emitted by the laser and it takes two directions: one goes through the gas chamber and the other goes through air in order to obtain a reference path. As the light goes through the gas chamber, a photo detector on the other side of the gas chamber detects it. The detector is connected to a power meter, which senses the power. As we do a wavelength sweep on the tunable laser, the detector will detect a drop of light power at certain wavelengths because the CO_2 gas has absorbed this light. These wavelengths correspond to the allowed molecular energy transitions between some hybrid rotational-vibration states. We have confirmed the results of the publication [1].

Importance of measuring CO_2

CO_2 measurement has many uses. Detectors can be used in highly populated rooms in order to detect the level of CO_2 and issue warnings when the level rises above a certain level. Excess CO_2 in our systems can cause drowsiness and headaches. CO_2 is the major greenhouse gas and its emission levels and presence in the atmosphere require monitoring. Another use of CO_2 emission is testing the total efficiency of hydrocarbon-fueled combustors. Medical applications include breath analysis.

Importance of measuring any gas

Our project has applications not only in detecting traces of CO_2 but detecting different gases provided the locations of their absorption wavelengths are known. For example, we can easily design a CO detector using the same principle as our CO_2 detector. Applications can lead to designing better fire detectors in homes or detecting other toxic gases from exhaust emissions.

Implications of Gas Absorption for LIDAR

Designing a LIDAR requires the knowledge of absorption lines of a gas it will be operating within. Our detector can help locate these lines and the LIDAR can be designed to function outside the absorption range.

According to the Beer's Law: $P \propto e^{-\alpha L}$, the power transmitted decays exponentially with distance. Thus, even if the measured short distance absorbance is low, the effect over distance can be rather dramatic. For example, 0.1% absorption in one meter leads to 1-.999(1000/1) = 63% absorption for 1 km and 99.995% absorption for 10 km!

Automated Measurement Setup

Fig. 2. shows how we used a computer equipped with LabVIEW to control the tunable laser and power meter. The program performed point-by-point wavelength sweeps near the 1.57 µm range with corresponding power measurements.

The equipment included Agilent 8164A/81682A Tunable laser based on a diode with an external cavity with built-in power stabilization, 0.1 pm resolution, and very narrow line width, and a Newport power meter with a near IR detector head.

Light was collimated using a high numerical aperture microscope lens and the free space path went through the gas under test.

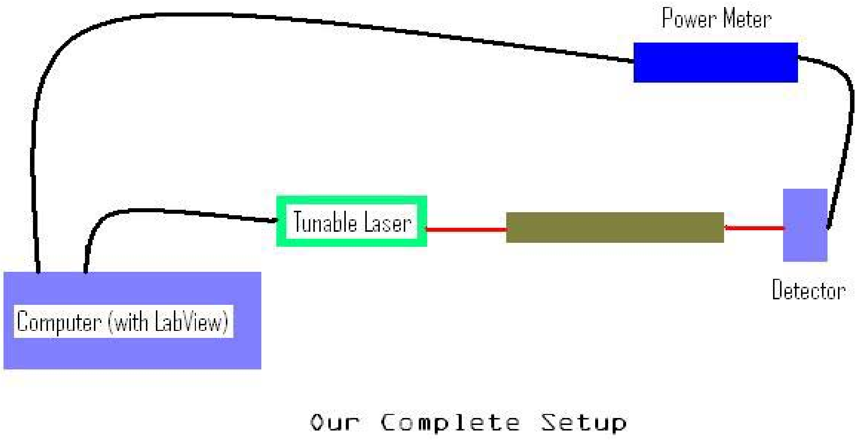

Fig. 2. Diagram of our setup.

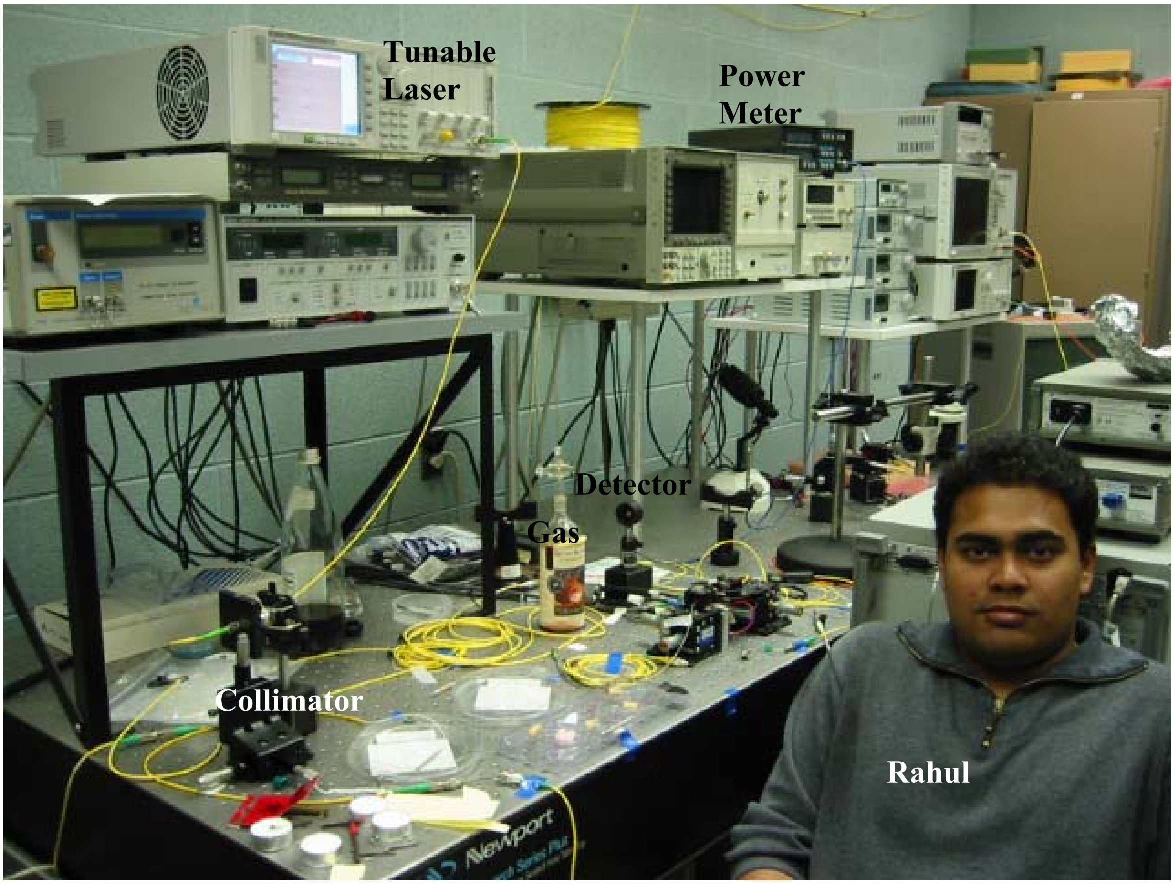

Figure 3. Photograph of the setup.

Optaining CO_2

Several ways of obtaing the test gas sample were considered and tried:
1) Exhaling into the T-connector in the middle of a meter-long PVC pipe.
2) Combustion of matches and paper at the bottom of a milk bottle.
3) Pepsi® poured into an empty mineral water bottle
4) Sealed glass vile with gas vile with gas under low pressure

Prior to automating the setup, balloons filled by exhalation with the Helium-filled reference were used. It is our belief that the balloons can yield good results in an automated setup, but they need to be carefully stabilized to keep a constant transmission path during the scans.

Results and Discussion

Figure 4 shows the reference scans obtained without the CO_2 sample in the path. The carbon dioxide concentration in the lower atmosphere is on the order of 300-400 ppm, which is not detectable at STP by our setup.

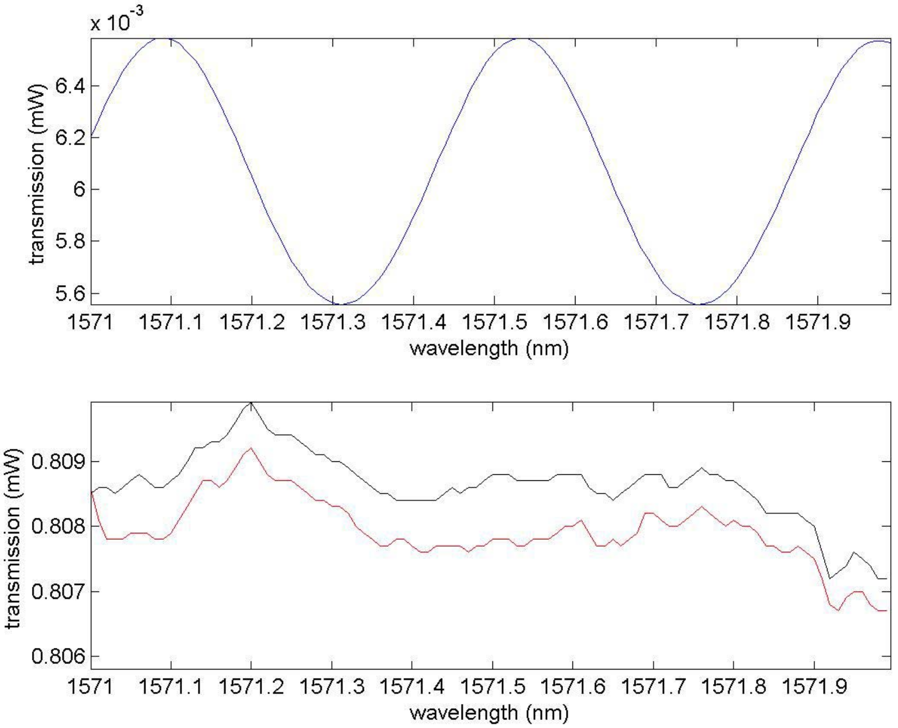

Figure 4. Power reference scans with and without attenuator.

The top graph shows the Fabry-Perot effect introduced by the attenuator attached to the detector head. After removing the attenuator the power reading variation with wavelength became much more constant. The lower graph shows two scans one (the lower values) without the PVC pipe in the path and the other with the pipe. The pipe probably helps collect and channel aberrated light resulting in a slight increase of detected power. By comparing the two scans, one can see that much of the fluctuation is systemic, and isn't true noise. One can estimated the noise level at ~0.3 μW or about 0.03% of the measurement.

The wavelength scans took about one minute. During which multiple exhalations into the pipe were made. Figure 5 is indicative of the process.

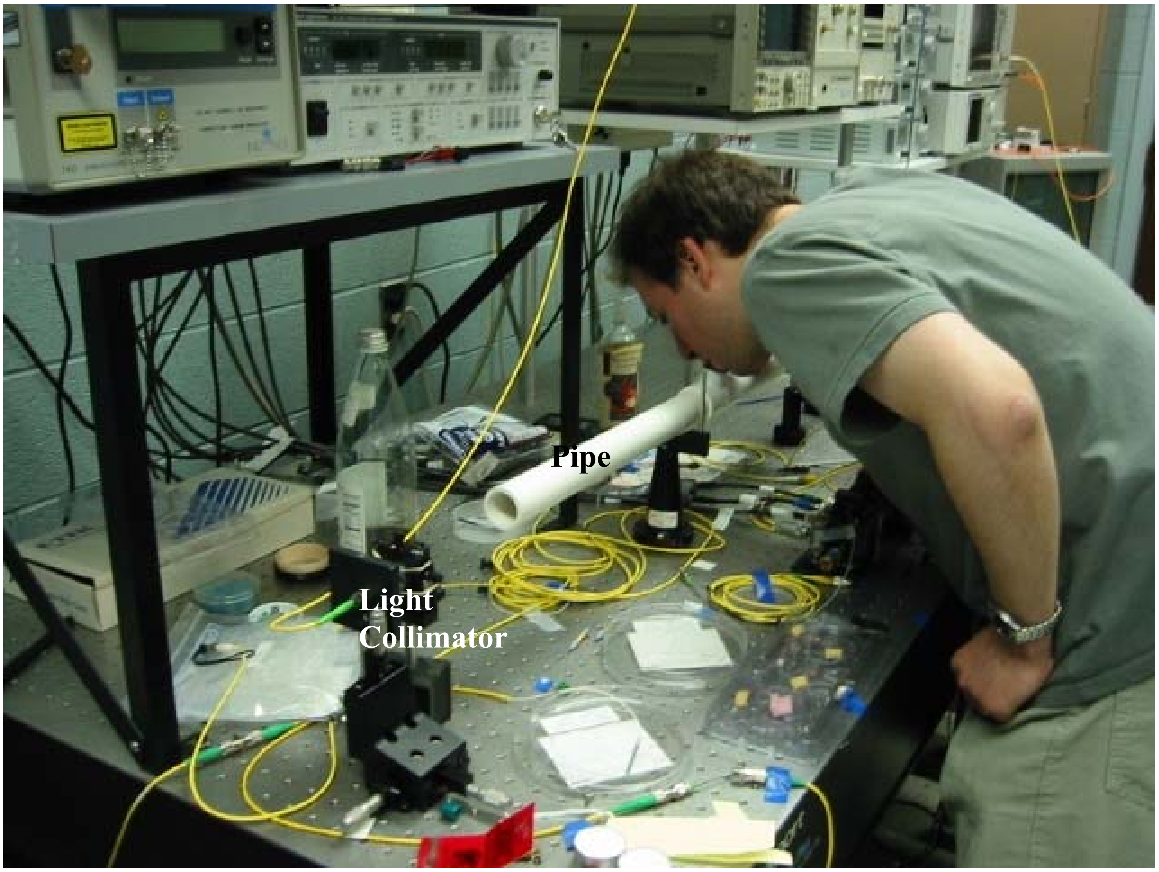

Figure 5. Carbon dioxide obtained by exhaling into a pipe.

The scans obtained during the exhalation CO_2 are shown in Figure 6. In the top portion of the figure two relatively long scans are shown together with the shorter scans representing attempts to focus on a single absorption line. We suspect that turbulence introduced by blowing into the pipe and the presence of water droplets and vapor in the exhaled breath introduced noise into the measurement. Although in retrospect we know that we observed the absorption lines, we weren't fully convinced after the measurement.

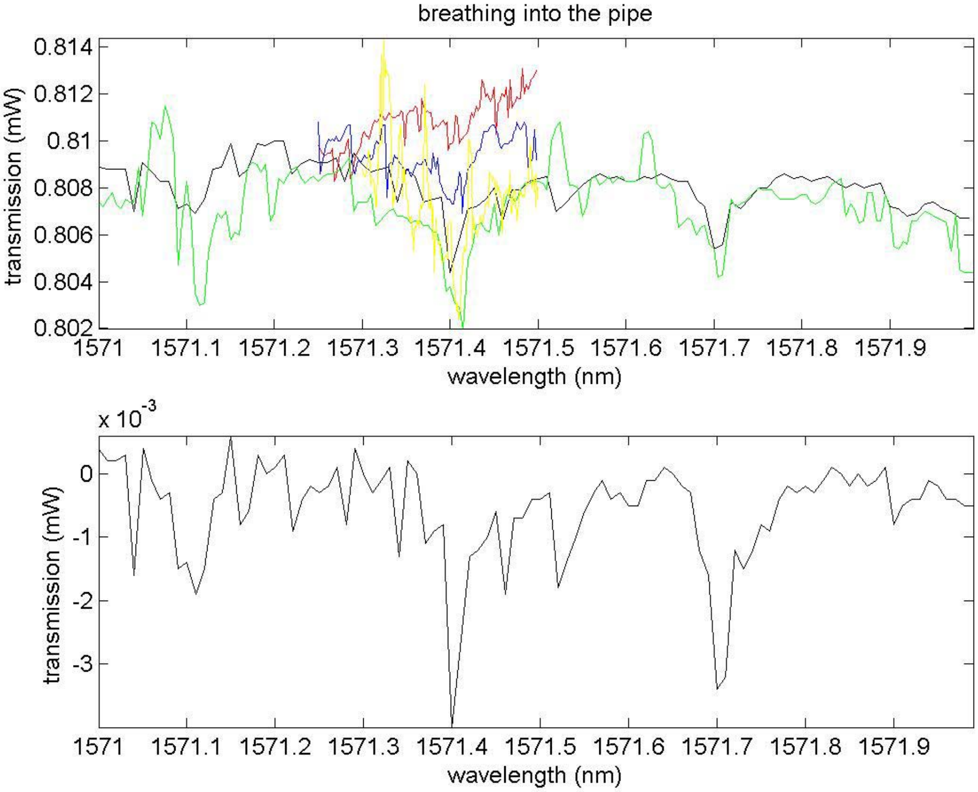

Figure 6. Measurement of the exhaled CO_2

The lower part of the figure shows the result of subtracting the reference scan. The dips appear more pronounced. In this measurement The dip at 1571.1 nm is weak. It is perhaps due to the fact that the pipe was not yet filled with the exhaled gas.

Figure 7 shows the measurement of CO_2 emitted during combustion of a match thrown into a milk bottle. The top portion is the reference scan through the bottle, showing that although power is lost, the measurement is very stable. The lower portion shows the observed absorption dips, especially clearly at 1571.4 nm. The variation in the dips is perhaps due to the fact that the fumes from the match did not fill the bottle completely at the time of measurement. We also attempted to burn paper in the bottle, but the resultant smoke sabotaged the measurement.

We next measured the vapors of Pepsi® Cola, which was poured from an aluminum can into a mineral water bottle which was subsequently closed. The top portion of Figure 8 shows the reference scan through the bottle in red and the scan with the cola in blue. The bottom is the difference of the measurement and the reference. It is interesting to note that the mineral water bottle showed dips at the expected locations of absorption lines. It is likely due to the slow accumulation of the CO_2 from the mineral water by the bottle through adsorption and diffusion.

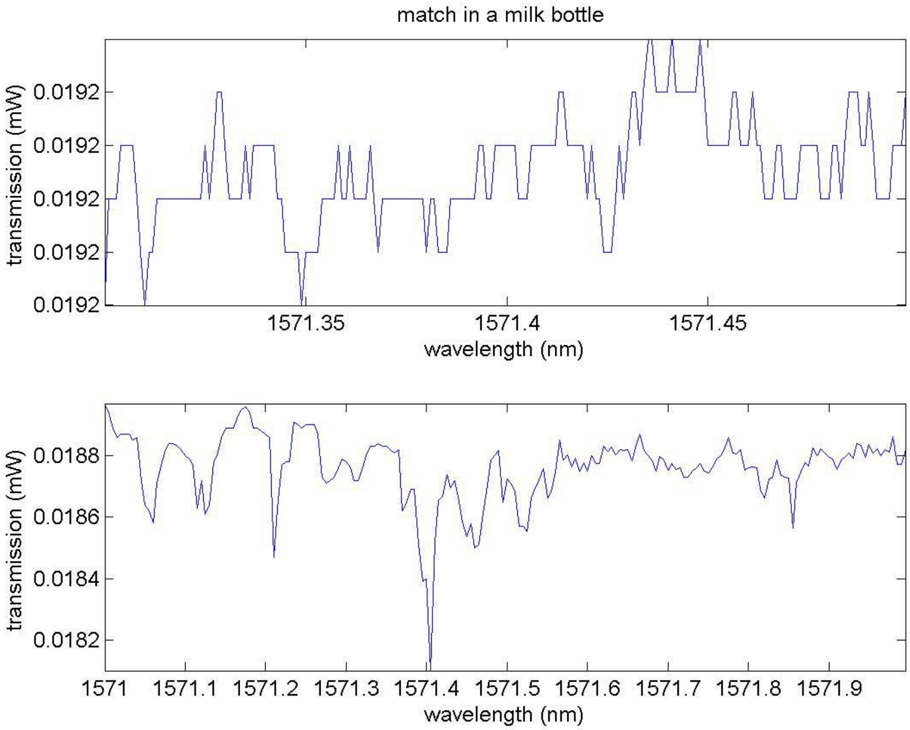

Figure 7. Measurement of CO_2 in combustion of a match.

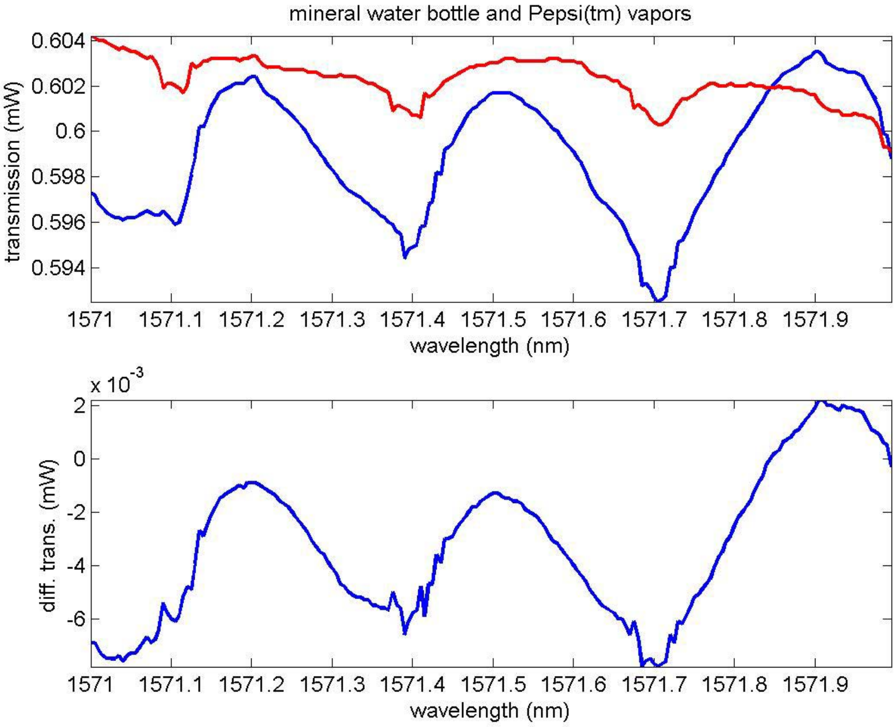

Figure 8. Measurement of CO_2 through cola vapors.

In order to confirm the results of the paper [1] we took a long scan covering the whole arm of the absorption spectrum. The resulting graph is shown in Figure 9. The upper part shows the raw data with the Fabry-Perot fringes introduced by the bottle along with the smoothed version. Subtracting the smoothed data from the original emphasizes the absorption lines which are very close to the ones reported in the reference paper [1].

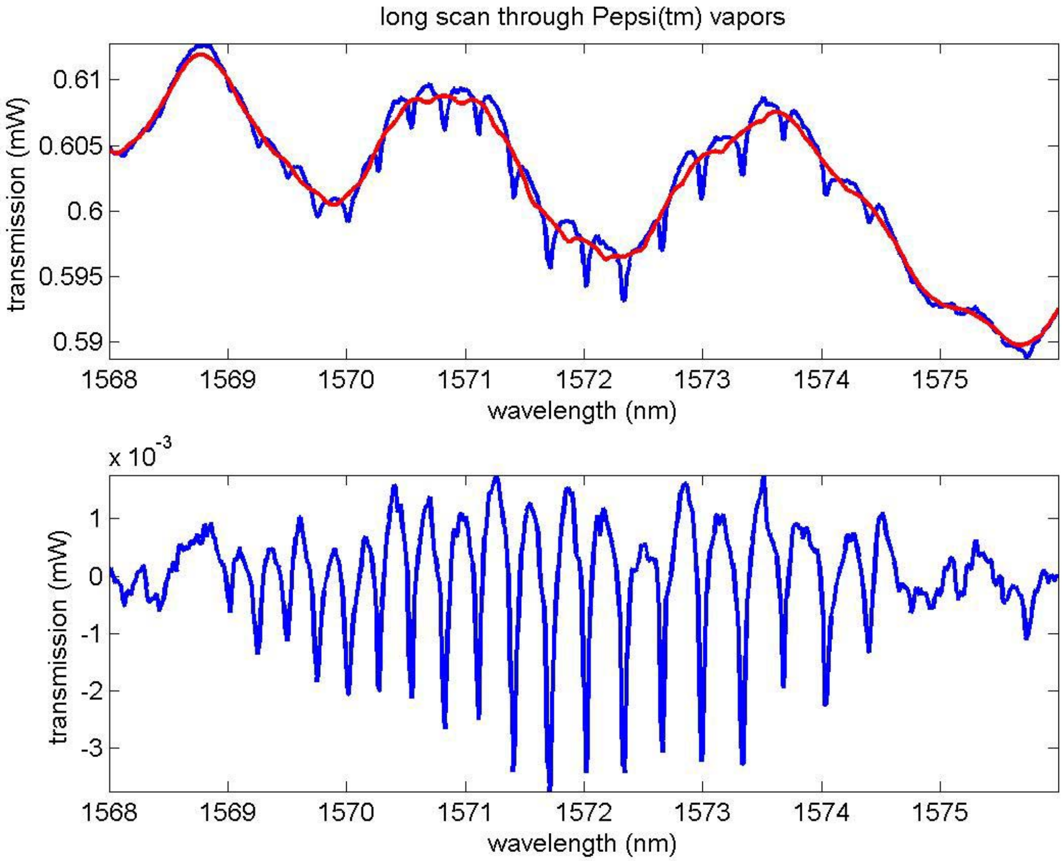

Figure 9. The CO_2 spectrum in cola vapors.

Although the measurement through the cola vapors showed good absorption spectrum, we obtained a flask filled with CO_2 at nominally 100 Torr pressure. The flask, shown in Figure 10, has a six centimeter diameter in the thickest spot. It has a stopper with a valve and all the joints have vacuum grease to keep the seal.

The scan through the flask is shown in Figure 11. The bottom portion shows the data with low-pass filtered (smoothed) version of the data subtracted. The locations of the lines is the same as in Figure 9, but the relative amplitude is not all correct, which is most likely attributable to insufficient sampling of the spectra in the frequency domain. The setup is capable of resolving these lines at the cost of slower scan times. The lines, are, of course, narrower than in Figure 9 due to lower pressure of the gas. The comparison of line widths at high and low pressures is shown in Figure 12.

Figure 10. The flask containing low pressure CO_2

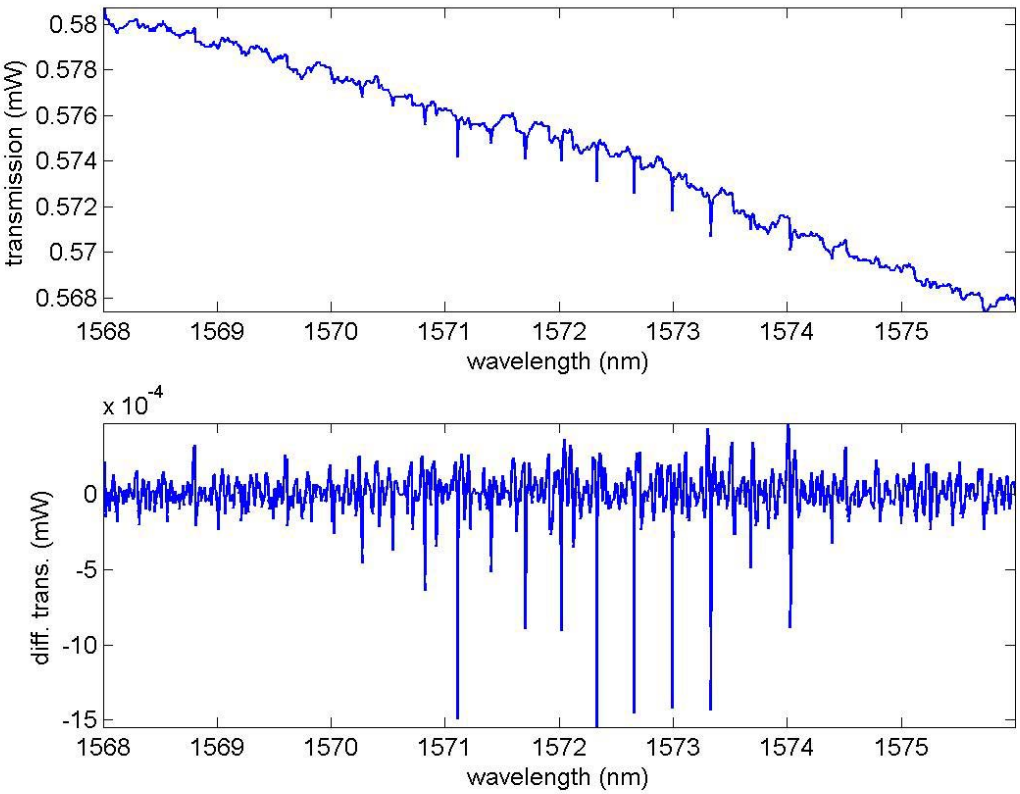

Figure 11. The measured absorption spectrum of low pressure CO_2

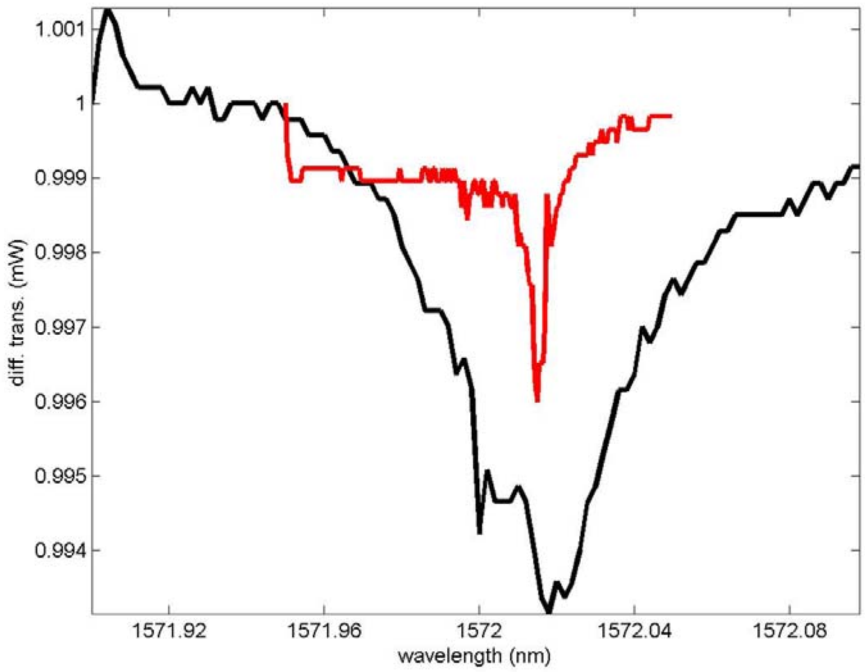

Figure 12. The comparison of line widths of CO_2 at low and high pressures

In Figure 12, the red represents the absorption line of the gas in the flask, which is nominally at 100 Torr, while the black line is the absorption line in a closed mineral water bottle which is under some pressure, since the concentration of CO_2 in the cola was not allowed to get to equilibrium when the can was opened. The ratio of the line widths can be estimated from the graph. The bigger is at about 0.04 nm or ~5 GHz, while the narrower one is about ten times smaller at ~0.5 GHz. With the line width proportional to pressure, the pressure in the mineral water bottle can be estimated to be 1000 Torr or about 1.3 Atm. It seems a bit large, but the estimate is rather crude.

Conclusion

We measured the absorption lines of CO_2 at1.57 μm wavelength. We also observed the effect of pressure on line width. Automation allowed us to easily measure absorbance below 1%. The setup can be further improved by introducing mirrors which fold the light path through the sample, and effectively increase the path through the gas. The experiment can be repeated for educational purposes.

Reference

D. M. Sonnenfroh and M. G. Allen "Observation of CO and CO_2 absorption near 1.57 μm with an external cavity diode laser," Applied Optics, Vol. 36, No. 15, May 20, 1997 p. 3298

Acknowledgements

Pete Dragic (ECE), Prof. Belford, Dave Engebretson, Prof. McDonald (Chemistry)