Beam path temperature determination for long distance measurements

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Abstract. Optical long distance measurements require knowledge of the refractive index to link the measured optical path length to the physical path length. For measurements in air the uncertainty of the refractive index determination reflects accuracy of the distance assessment. Edlen's equation provides means to determine the refractive index of air if temperature, pressure, and composition are known.

This paper presents a setup built towards obtaining the temperature of the medium the light propagates through by monitoring the changes in the absorption spectrum.

Keywords. Absorption spectroscopy, virtually imaged phased array (VIPA), long distance measurements.

1 Introduction

In optical distance measurements, the measured distance is the product of the physical path length, and the refractive index of the medium the light has propagated through. Edlen reviewed measurements from different sources and provided an equation, with the help of which the refractive index of air could be calculated over a wide parameter range (Edlen (1953)). The equation has been improved in a subsequent publication by the same author, incorporating new data, see Edlen (1965). Pressure, composition (such as water vapour content), and temperature show the strongest influence. Reliable measurements of these parameters are needed for calculating the refractive index and consequently the link between physical and optical distance. This improves the obtainable accuracy of long distance measurements in air, which are currently limited by the undetermined refractive index variations as one of the factors. Optical measurements can measure the temperature directly on the beam path, circumventing a major drawback of thermometer arrays that are limited to measure in the vicinity of the beam.

In this work we aim to develop such a measurement technique. The presented setup will attempt to measure temperature changes by looking at the changes in the absorption profile while keeping the pressure and composition constant. To determine the feasibility of this method we measure in a controlled atmosphere, a closed gas cell, instead of ambient air. If successful the setup can provide the first step to an alternative to thermometer arrays along the beam path for optical long distance measurements, such as Cui (2009), Cui (2011), and van den Berg (2012).

2 Absorption Spectroscopy

Spectroscopy is the act of gaining insights in the structure of matter by looking at its interaction with light. In the case of absorption spectroscopy the absorption of light at certain wavelengths after passage through a medium is investigated. Several databases predicting the absorption of ambient air are available. From the selection of those we chose the HITRAN database. Figure 1 is showing the simulated data for 1.5 m of pure CO_2 at atmospheric pressure and room temperature as well as the difference in absorption when increasing the temperature by 5 K.

From Figure 1 it is clear that the expected changes are in the sub-percentage scale, setting requirements for the noise level of the setup. However, a signal can be obtained as long as the setup performs sufficiently well

3 Setup

The setup is built to do spectroscopy at two different wavelengths for testing two gas species (O_2 and CO_2) simultaneously. Visible light (VIS) was obtained by frequency doubling of the infra-red (IR) light emitted by the erbium-doped fiber based

frequency comb (FC) laser. This was done with the aim of detecting O_2 since the laser wavelength is far from the $_{O2}$ spectral lines. The CO_2 wavelengths lie within the laser emission range. A schematic of the setup can be found in Figure 2.

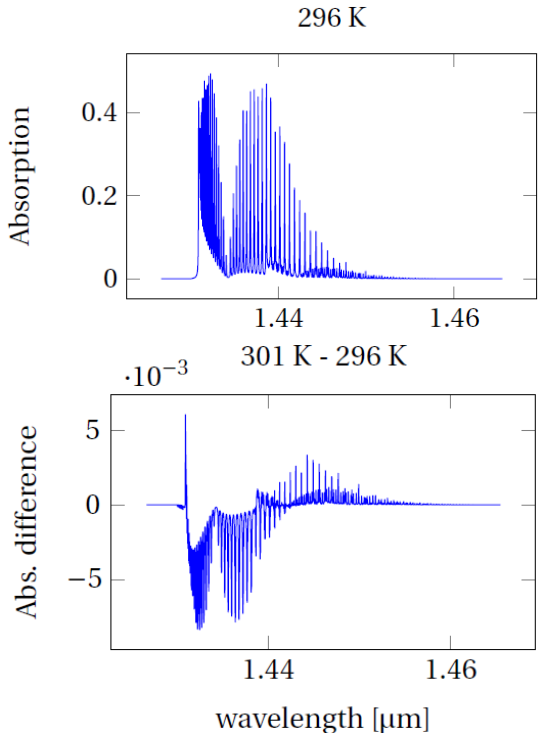

Fig. 1 (top) Absorption spectrum after passing through 1.5 m of pure CO_2 at atmospheric pressure and a temperature of 296 K as obtained by HITRAN. (bottom) Difference in absorption for the same gas when changing the temperature to 301 K

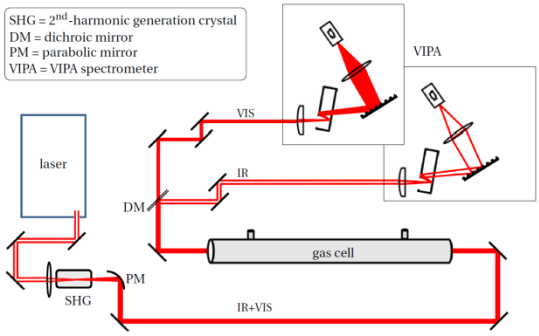

Fig. 2 The setup uses an IR FC laser source. Visible light is created by focussing on the second order nonlinear crystal. IR and VIS share the same beam path until they are separated by a dichroic mirror guiding each of them to the respective spectrometer

Both wavelength regions can be collimated with a parabolic mirror and share the same beam path in the medium ensuring the same volume under test. Two nearly identical spectrometers have been built with components operating at 1550 nm for CO_2 and 760 nm for O_2 respectively. The gas cell is of 1.5 m length and can be controlled with mass flow and pressure controllers. A temperature sensor has been placed within the gas cell. To take a spectrum the gas cell has to be filled with a neutral background, which was N_2 in our case. N_2 does not show absorption at wavelengths under test.

3.1 Virtually imaged phased array (VIPA)

For the detection of absorption we used VIPA spectrometers. These spectrometers consist of a combination of VIPA etalon as high resolution angular disperser and a grating, which acts as a pre-disperser. The combination enables high resolution spectroscopy without sacrificing free spectral range (FSR), i.e. the ambiguity range after which two wavelengths can produce the same output on the spectrometer. Further details on the working principle of the VIPA etalon can be found in Xiao (2004).

A broadband laser source will produce a line pattern on the camera, which has to *stitched together* to obtain a line spectrum. In order to do this FSR and reference wavelength have to be determined as part of the calibration procedure. This can be done with the help of a single mode laser of known emission, which will show a spot on the VIPA image reappearing after one FSR. Alternatively the spectrum of a known gas species such as in a laser reference wavelength gas cell can be used for calibration. A typical image is shown in Figure 4.

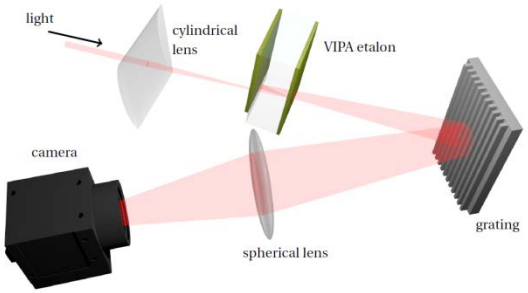

Fig. 3 VIPA spectrometer consisting of VIPA etalon and a grating as pre-disperser.

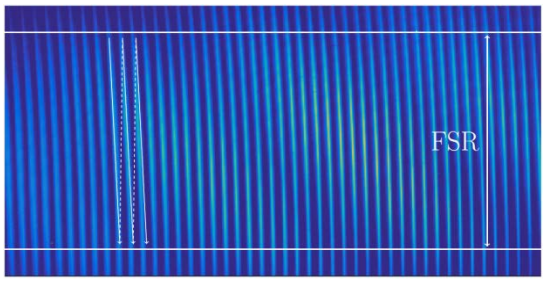

Fig. 4 Typical camera image of broadband laser passing through a VIPA spectrometer. Information is contained within the FSR length of one VIPA line. To access a broader range the neighbouring lines have to be concatenated.

4 Measurement and results

At present we have achieved the detection of both O_2 and CO_2 absorption spectra. In both cases the gas cell has been filled to atmospheric pressure with pure O_2 or CO_2 respectively. For the temperature comparison a Pt sensor has been inserted into the gas cell. Camera noise as well as fluctuations of the cavity due to the evacuation procedure prevent meaningful temperature predictions from the measured spectra. This is especially true for the O_2 measurements (see Figure 6), but can also be seen in the measured CO_2 transmission spectrum (Figure 5). These issues need to be resolved before attempting measurements at higher temperatures. Methods of obtaining a reference signal without evacuation of the gas cell are currently being investigated, which is believed to be the main source of fluctuations in the measurement protocol.

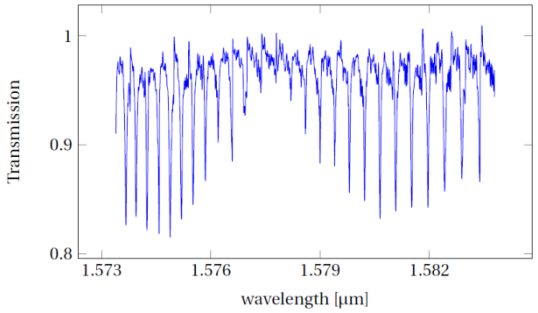

Fig. 5 Measured line spectrum for 1.5 m light propagation in CO_2 at 27° C and atmospheric pressure. The signal shows fluctuations up to 5% at the baseline preventing temperature estimations.

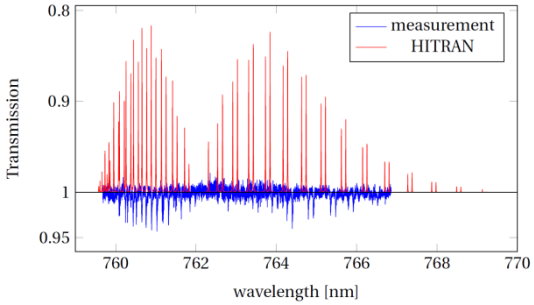

Fig. 6 Measured line spectrum for 1.5 m light propagation in O_2 at 27° C and atmospheric pressure. The measured transmission is off by a factor of 4 with respect to the expected results as well as showing a noise level that forbids temperature estimations.

Acknowledgement

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