Absorption spectroscopy

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In this experiment we were interested in studying two techniques implementer in absorption spectroscopy, direct absorption spectroscopy and Wavelength-modulation spectroscopy. We first are interested in measuring the concentration of O_2 in air by capturing the absorption signal at different sample lengths. Then we wanted to study what is the path length traveled inside a highly scattering medium trying to see how light can get absorbed inside of a solid that has a lot of air pockets in it. With this measurements we can understand how to detect changes in oxygen concentration if we have previously determined that path length.

I. INTRODUCTION

In the present laboratory practical direct absorption spectroscopy is used while utilizing a tuneable diode laser for measurement of oxygen (O2) concentration. The diode laser is scanned across an absorption line in the so-called A-band of O2, located near 760 nm, and the oxygen concentration is determined at different path lengths by analysing the recorded spectrum using the Beer-Lambert law. We also calculated absorption path length of the scattering material.

II. THEORETICAL BACKGROUND

Here we used direct absorption spectroscopy in which Laser light is shined directly to the sample, here our sample is air molecules. Light transmitted through this sample is detected. A narrowband tenable LASER is used for this purpose. Intensity of transmitted light measured by detector and Laser light before passing through the sample are related and are given by Beer Lamberts Law.

$$I(\nu) = I_0 e^{-\alpha(\nu)L} \tag{1}$$

Where $I(\nu)$ transmitted light after passing through sample, I_O Intensity of light before passing through sample, $\alpha(\nu))$= absorption co-efficient (units are given cm^{-1}) and l=length of sample cell. Its also known that $\alpha(\nu) = N\sigma(\nu)$ and substituting in beer lambert law and we get:

$$I(\nu) = I_0 e^{-N\sigma(\nu))L} \tag{2}$$

Where the number density of absorbing atoms/molecules is given by N with units of molecules/cm^3 and $\sigma(\nu)$ is the frequency-dependent absorption cross section. The oxygen A-band is the transition $\mathrm{b}^1\ \Sigma_g^+(\nu'=0) \leftarrow \mathrm{X}^3\Sigma_g^-(\nu''=0)$, i.e. a transition between the lowest vibrational level, $\nu''= 0$, of the electronic ground state,$\mathrm{X}^3\Sigma_g^-$ and the lowest vibrational level, $\nu'= 0$, of the second excited electronic state, $\mathrm{b}^1\ \Sigma_g^+$ is the transition we are interested in studying in this experimental setup giving, thus giving us a precise requirement on the setup needed to study this absorption signal.

We used wavelength-modulation spectroscopy technique with the help of this technique wavelength of the laser light can be modulated at a relatively high frequency (typically ≈10 kHz) at this modulation frequency the absorption light is evaluated. As noise are more sensitive at low frequencies and can be find out as 1/f. with the help of WMS we can reduce noise as detection is now at much higher frequencies where noise is lower. Fourier analysis or lock-in amplifier is used for this detection.

III. EXPERIMENTAL METHOD

Firstly, we used tuneable diode laser produced in a saw toothed function at specific current and temperature. The laser was then aligned with the help of focuser and allowed to pass through air molecules and then it was collected with the help of photodiode.

We set three different path lengths, 167.5, 104 and 12 cm and we calculated concentration percentage of O2 molecules in the air and signal to noise ratio. Then scattering material is used of 3,5cm thickness and Laser light is allowed to pass through it while changing path length, we chose 5 different points. Path lengths Lair= 23, 60,5, 80,5, 107 and 127,5 cm are used. We apply the Fourier transform to the absorption signal, we do this because we reduce the noise in the absorption signal and we can extract a large set of information about the absorption form the different harmonics of the Fourier transform . Generally the second harmonic 2fAmp is used because it is strongly dependent on the spectral parameters and gas properties an can be compared to simulations, with this in are experiment we modulated the absorption signal is calculated at these 5 different points and L_{sample} is calculated.

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IV. RESULT & ANALYSIS

The first set of measurements where done looking at the direct absorption signal from an O_2 sample at different lengths. Since we are just trying to find the concentration of oxygen in air we just looked at hoe the absorption signal change at different length from the light source. The data recollected is shown in Figure.1 where we can see that there is a significant change in the absorption signal between different lengths.

As described before we executed three measurements at different length first we looked what type of signal we get when there is a short distance or a small sample cell length of 12 cm, from the figure we can see that we have a very weak signal, but as we gradually make the cell length larger we have a well define absorption signal.

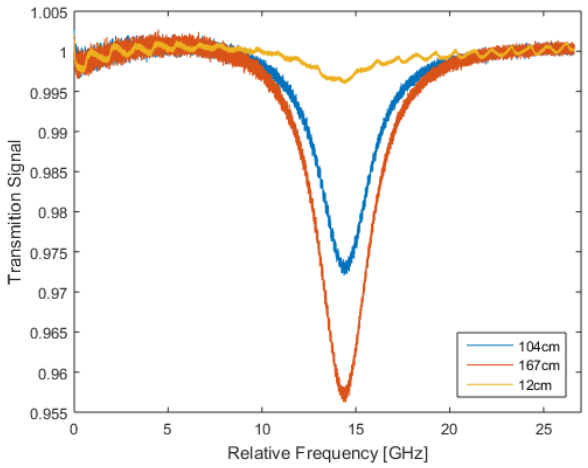


FIG. 1: Absorption signal for an air sample implementing direct absorption spectroscopy technique. We can tell that we have a better signal when there is a longer sample length.

By analyzing the parameters of the cavity length and the etalon in the Fabry Perot interferometer we could find that the free spectral range of the system was $\Delta v_{FSR} = 1.09387GHz$, with this and the recollected data we got Figure.1.

From this we compute the absorption percentage, the signal to noise ratio and the concentration of O_2 in air. This data is shown in Table.I, where the best signal as expected form Figure.1 was for the longest sample length 167 cm.

Direct Absorption			
Length	Abs.	SNR	O_2
12 cm	% 0.4	2.67	% 24.3
104 cm	% 2.75	18.33	% 19.55
167 cm	% 4.35	29.06	% 19.41

TABLE I: Data recollected from the absorption signal shown in Figure.1 implementing Equation.2

With this we proceed to study the Wavelength-modulate technique inside of a highly scattering medium, which in these case is polystyrene foam. The real length of this sample is 3.5 cm, and we are going to find its optical length by studying its absorption signal at different lengths.

The recollected data for two lengths of an air sample is shown in Figure.2 where we are measuring the 2f signal which is proportional to the absorption signal. We can see that we have the same tendency as in direct emission when there is a longer sample length we have a large absorption signal.

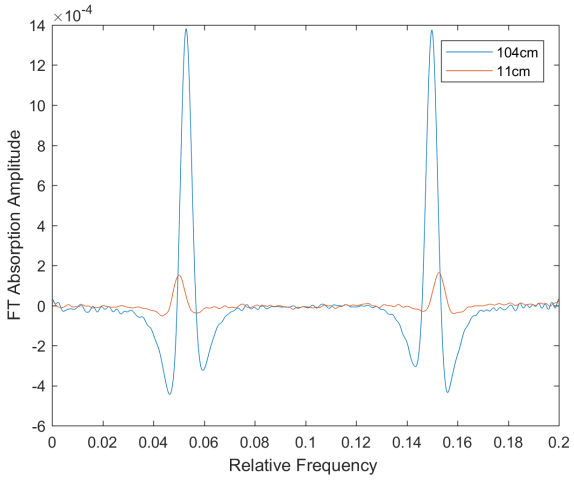


FIG. 2: Absorption signal for an air sample, where we can see that the absorption signal increments with the length of the sample.

With this insight now we proceed to execute the measurement of a scattering medium at five different lengths. The recollected data for the five measurements is shown in Figure.3 where we plot the peak of each absorption signal against the length we collected it at, then a fitting was done to find the path length inside of the scattering medium as we know that the absorption of the medium should be zero we just find the intersecting point with the x axis.

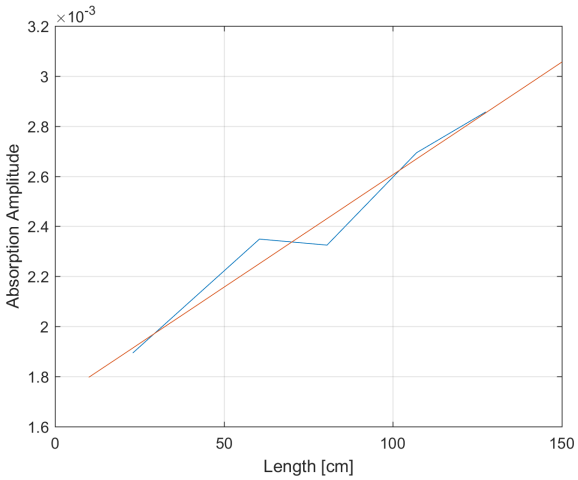


FIG. 3: Absorption signal against collected length where the fitting lets us find the path length inside of the scattering medium

From the fitting we can find that the path length inside of the scattering medium is 189.8 cm which shows how the light travels for a long time inside of the material before its able to get go threw the other side.

V. DISCUSSION

From the data recollected we can see the strength of this set of techniques to measure absorption signals, in the case of direct absorption we can see how there is a directer connection between the sample length and the absorption signal. For the wavelength modulation there is a clear advantage at the time of measuring absorption signals in scattering medium. For both techniques presented premising results in this experiment.

In the directer absorption are main goal was to find the concentration of oxygen in air, for dry air we can find in literature that there is a %20.9 concentration. In are measurement we can determine that for are best absorption signal given at 167 cm we have concentration of %19.41 which has an error of %7.12. This error has have multiple factors of production, first it wasn't taken at the controlled conditions and there were multiple source of out side radiation being detected. Besides this we have a small error which is a promising result for a quick measurement of the concentration in a relatively simple setup.

In the wavelength modulation we observed the power of measuring absorption signals threw solid materials the present high scattering. We also measured the optical length of one of this materials, giving us a length of 189.8 cm and the real length was 3.5 cm , thus having 54.2 time longer optically. With this technique we can construct a standard form of measurement to determine changes in concentration since the dependence of the absorption is linear. For this experiment we were able to implement basic setups that show the strength of absorption spectroscopy in different scenarios.

[1] Atomic and Molecular Spectroscopy (FAFF08/FYST14), "Absorption spectroscopy", laboratory guide 2018.

[2] S. Svanberg, "Atomic and Molecular Spectroscopy", Advanced Texts in Physics, 2004.