 Simulation of Second Harmonic Based on Optical Fiber Sensor

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Abstract. This paper is based on the Lambert-Beer law and the differential optical absorption method is used to measure the concentration of methane gas. Simulation of the whole experiment is carried out by using MATLAB. Sine waves with periodic changes are simultaneously superimposed on triangular waves are simulating the light source in the experiment. Adding harmonic modulation to eliminate the interference of noise and fundamental components obtain the second harmonic components which carrying the concentration information. Finally, different concentration will bring the second harmonic voltage value. Records are corresponding with concentration of the second harmonic voltage value. Experiments show that the resulting second harmonic signal can meet the gas detection requirements.

1. Introduction
When light passes through the gas, the gas molecules absorbed by light of certain wavelengths. Light passes through the gas and the light intensity attenuates weakly. Although this attenuation is weak, concentration can still be measured by measuring the attenuation of light intensity Beer-Lambert's law describes the phenomenon of light intensity attenuation [1].

Based on the gas spectrum absorption theory, the technique for analyzing the absorbed gas concentration information is based on the synchronous detection using a harmonic voltage signal of a lock-in amplifier having a phase difference of 90° from the target gas modulated signal. By slowly modulating the emission wavelength stabilized at the absorption peak, the first harmonic signal is proportional to the first derivative of the gas absorption line through zero. The second harmonic signal peaks at this point and gives the second derivative profile of the gas absorption line [2].

2. Absorption gas sensor second harmonic
The differential absorption optical path is as follows: a light beam passes through the gas chamber containing the gas to be measured as a measurement signal after the incident light is split into two beams, and the other gas passes through the reference gas chamber (filled with inert gas: nitrogen gas) as contrast signal. Difference between the two signals sent to the lock-in amplifier modulation, measuring their second harmonic voltage values, resulting in gas concentration information. The system diagram is shown in Figure 1.

The advantage of this method is that it can effectively eliminate the interference of the optoelectronic components such as drift and temperature drift on the optical path and the influence of the instability of the output of the optical source on the measurement result as well as the external...
noise and other uncorrelated signals in the optical path in order to determine the overall optical design of the experimental program.

3. Second harmonic analysis based on lock-in amplification
The laser emits a light wavelength that is always stable at the absorption peak, and the slow modulation signal at the light source drive is canceled, resulting in a transmission signal whose amplitude depends on the gas concentration [3]. The spectral parameters of the absorption line determine the intensity of the second harmonic signal, that is, the second harmonic signal contains the gas characteristics. The use of second harmonics to detect gas concentrations has many advantages: the second harmonic signal (2f) is sensitive to the spectral shape of the absorption line rather than the absorption value and due to the use of phase-locked phase-sensitive detection, the laser intensity and electronic device. The associated noise is that the intensity modulated signal of the diode laser is the strongest in the 1f signal as the noise falls outside the lock band after passing the filter. Therefore, it can be used to normalize 2f to eliminate noise related to laser signal drift, scattering or beam deviation [4] [5].

In this paper, LIA is used to detect the amplitude of the second harmonic to obtain the gas concentration information. The theoretical analysis shows that the amplitude of the second harmonic has a linear relationship with the gas concentration.

4. Absorption in the optical path of the second harmonic signal system simulation
The process of modeling the system is to use the Beer-Lambert theorem, the modulation scheme of the wavelength modulation spectrum and the lock-in amplification and demodulation scheme by using the mathematical formula combined with the module building model in the simulation program Simulink. The simulation model of methane optical fiber sensor based on wavelength modulation, lock-in amplification and second-harmonic detection demodulation is shown in Figure 2.
The parameters of the simulation model are as follows: intensity modulation coefficient \( m = 0.35 \), wavelength modulation coefficient \( n = 0.037 \), gas chamber length \( L = 2 \text{cm} \), absorption peak wavelength is 1653.7 nm.

Figure 3 shows the low-frequency triangular wave and high-frequency sine wave superimposed on the modulation signal. We can see that the methane absorption coefficient changes with the periodic changes in the modulation signal. In the experimental simulation, we use the periodic sine wave signal superimposed triangular wave as a system of light. In the simulation of differential absorption, two signals are simulated. According to the Beer-Lambert law, the incident light from the light source enters the optical path of the light to be measured and passes through the gas to be measured and there is a slight absorption.

![Figure 3. Light source drive waveform](image1)

![Figure 4. Absorbed waveform](image2)

**5. System simulation results analysis**

Figure 4 shows the change of light intensity of the gas chamber, when the methane gas volume fraction is set to 0.1. Experimental simulation, we use the periodic sine wave signal superimposed triangular wave as a system of light source. In the simulation of differential absorption, the incident light emitted from the light source according to the Beer-Lambert law enters the optical path of the light to be measured and passes through the gas to be measured and there is a slight absorption. After the difference between the reference optical path and the optical path to be measured, the external
interference signal such as noise is eliminated, but the intensity of the optical signal has also been weakened. In order to ensure that the signal amplitude is not excessive but also to strengthen the detection of the second harmonic signal carrying gas concentration information, we adopt a lock-in amplifier.

Detection of gas chamber light intensity with the modulation signal changes at the same time, and its change cycle and trend are the same as the modulation signal. Detection of light intensity at half the height of the image appeared obvious absorption phenomenon, and showed a cyclical change, the same cycle and modulation signal. Figure 5 shows the second harmonic image of the signal after the detection of the gas cell. It can be seen that the outline of the image is relatively vague because of the introduction of the component of the triangular wave at this frequency.

The peak-to-peak $V_{pp}$ of the second-harmonic signal and the second-harmonic wave obtained by amplifying the signal $10^5$ times at different concentrations.

When $C_1=CC=0.5ppm$, $V_{pp1}=1.2774e-06(v)$; when $C_2=CC=1.0ppm$, $V_{pp2}=2.5549e-06(v)$;

Figure 5. Second harmonic signal at $CC=0.5ppm$

When $C_3=CC=1.5ppm$, $V_{pp3}=3.83234e-06(v)$; when $C_4=CC=2.0ppm$, $V_{pp4}=5.1097e-06(v)$;

Figure 6. Second harmonic signal at $CC=1.0ppm$

When $C_5=CC=2.5ppm$, $V_{pp5}=6.3871e-06(v)$.

Figure 7. Second harmonic signal at $CC=1.5ppm$

Figure 8. Second harmonic signal at $CC=2.0ppm$
Figure 9. Second harmonic signal at CC=2.5ppm

The corresponding second harmonic amplitude at different concentrations

Figure 10. The corresponding second harmonic amplitude at different concentrations

It can be seen from the above five sets of data (Figure.5-Figure.9) that within a certain range, the gas concentration is related to the peak-to-peak value of the second harmonic signal, and is proportional to the ratio. As shown in Figure.10: A linear relationship can be obtained by analyzing the peak-to-peak values of the second harmonics of these concentrations and their corresponding outputs. Using the collected data to fit the linearity between the concentration and the second harmonic voltage, one-to-one correspondence is obtained. Experimental results show that this method of tutor data, good linearity. The reason is: differential absorption through the differential filter out a large number of signal interference signals, and direct absorption of these signals are still there, the measured value of the second harmonic voltage interference. Difference absorption curve obtained as a measure of the concentration of the standard curve. Simulation shows that the linearity is high, so the experimental scheme is reasonable.

6. Conclusion
In this paper, based on the Bill Lambert law, the differential optical absorption method is used to
measure the concentration of methane gas. The experimental simulation process uses MATLAB to complete the gas absorption process, and the second harmonic is collected using the method of lock-in amplification. After locking the amplified signal, the larger weakened the higher amplitude of the fundamental signal, the resulting second harmonic signal to meet the gas detection requirements.

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