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Study on Optical Fiber CO Gas Sensor Based on Difference Absorption

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Abstract. By analysing the near infrared spectral absorption of CO molecule and considering factors such as compatibility with the transmission characteristics of silica optical fiber and the price, a kind of all-fiber remote sensor utilizing Fiber Bragg Grating (FBG) filters and 1.567μm high power light-emitting diode (LED) was developed for real time absorption measurement. And a novel faint signal detective method by using a digital phase sensitive detector (DPSD) is designed. FBG has a low insert loss and can be produced easily compared with dielectric interference filters. Theory and experiment proved that the system has simple construct and high sensibility.

1. Introduction

The environment pollution caused by carbon monoxide gas releasing from boiler or other burning has become more serious along with the development of industry, and in the situation of coal gas or mine working the poisoning accident happened frequently, so it has vital significance to measure the concentration of carbon monoxide gas in these situation accurately and real-time.

With the rapid development of optical fiber communication technology, low-cost and high quality near infrared light emitted diode working at room temperature become widely available. Study on optical fiber gas sensor has become very pop. Optical fiber sensor system can fulfill on-line measurement in high-temperature, poisonous and dangerous situation where human being and traditional instruments can hardly accomplish [1-4].

In this paper, using FBG filters to replace the traditional interference filter, a novel difference absorption sensing system was developed.

2. Principle of Gas Difference Absorption Measurement

According to Lambert-beer law, when the light wave passes through the gas, take the interference of light way into account, the transmission intensity can be expressed as

\[ I(\lambda) = I_0(\lambda)K(\lambda) \exp[-\alpha(\lambda)Cl + \beta(\lambda)] \]

(1)

In this formula, \( I_0(\lambda) \) is the intensity of monochromatic light whose wavelength is \( \lambda \) before it enters the gas cell; \( I(\lambda) \) is the intensity of the exit light; \( \alpha(\lambda) \) is the absorption coefficient of per unit concentration and per unit length gas under certain wavelength; \( C \) is the concentration of the measured gas; \( l \) is the length caused by interaction of the measured gas and light; \( \beta(\lambda) \) is the light way’s interference coefficient; \( K \) is a proportional coefficient[2].
Because β(λ) is a random variation, it is difficult to determine C (the concentration of the measured gas) only by this formula. If two kinds of monochromatic light whose wavelength (λ₁, λ₂) are very close but differ greatly in absorption coefficient, pass through the measured gas at the same time or in a very short time, and adjust the optical system properly to ensure \( K(\lambda_1)I_0(\lambda_1) = K(\lambda_2)I_0(\lambda_2) \), we can obtain

\[
C = \frac{1}{[\alpha(\lambda_1) - \alpha(\lambda_2)]} \ln \frac{I(\lambda_2)}{I(\lambda_1)}
\]  

(2)

In practical application, the light which takes \( \lambda_1 \) as its wavelength is corresponding to the absorption spectrum of the gas, while the light which takes \( \lambda_2 \) as its wavelength doesn’t be absorbed by the detected gas (that is reference wavelength), so it is an empty value in the testing process. There is \( R(\lambda_1)/R(\lambda_2) < 1 \), unfold \( \ln I(\lambda_1)/I(\lambda_2) \) in Taylor series.

The gas concentration can be expressed as

\[
C = \frac{1}{[\alpha(\lambda_1) - \alpha(\lambda_2)]} \frac{I(\lambda_2) - I(\lambda_1)}{I(\lambda_2)}
\]  

(3)

Under the wavelength of \( \lambda_1 \) and \( \lambda_2 \), if \( \alpha_1 \) and \( \alpha_2 \), the absorption coefficient of the gas can be measured, the concentration can be obtained from the gauge of \( I(\lambda_2) - I(\lambda_1) \) and \( I(\lambda_2) \).

3. Design of Optical Fiber Sensor System

According to the basic optical characteristic of FBG, only the optical light satisfying with the Bragg formula \( \lambda_B = 2n_{eff}/\Lambda \) can be reflected intensely [5]. Here, \( \lambda \) is Bragg wavelength, \( \Lambda \) is period of the grating and \( n_{eff} \) is the sufficient refractive index [5]. Using Fiber Bragg Grating (FBG) as a optical filter, the system block diagram is showed as below.

![Figure 1. System block diagram of optical fiber sensor.](image)

In Figure 1, The light emitted by LED enters into the gas cell through coupler and transmission optical fiber, the exit light from gas cell goes to FBG1 through the coupler and transmission optical fiber, the optical light ray with \( \lambda_1 \) wavelength is reflected to PIN1, the rest goes to FBG2 and the optical light ray with \( \lambda_2 \) wavelength is reflected to PIN2. Then two beams of light influx in the PIN are converted to electric signal. Carrying through sampling to analog signals by S/H and then convert them to digital by A/D. LED is drive by the modulator with the frequency \( f \) and \( f \) also is the frequency of the reference signal. Processing with compute by soft programme to realize the work of Lock-in amplifier, and then display the output [6].
4. Experiment Results
In the experiment, the device described as Figure 1 was adapted. According to the absorption spectra of CO molecule, it has absorption line which wavelength equal respectively 4.66μm, 2.2μm, 1.567μm. Considering factors such as compatibility with the transmission characteristics of silica optical fiber and the price, 1.567μm was selected as the measurement wavelength, and let the central wavelength of FBG1 equal 1.567μm, and the central wavelength of FBG2 was selected as \( \lambda_2 = 1.53 \) μm.

When the concentration of CO is 0%, adjusting the light path to let \( K(\lambda_1)I_0(\lambda_1) = K(\lambda_2)I_0(\lambda_2) \). And injecting CO standard gas with different concentration, reading the output voltage value of two lock-in amplifiers, the concentration of methane gas can be gained by the formula below

\[
C = \frac{1}{\alpha(\lambda_1) - \alpha(\lambda_2)} \frac{V_2 - V_1}{V_2} = k \frac{V_2 - V_1}{V_2}
\]

In the formula, \( V_1 \), \( V_2 \) represented the output of two lock-in amplifier respectively, and the coefficient \( k \) can be seek by measuring the different concentration CO gas with linearity regression method.

In the demarcating experiment, set the full measurement value is 15%, using different concentration standard mixture gas of CO and nitrogen gas, the experimental data showed as below

| Standard value \( C_s \) (%) | Measurement value \( C_m \) (%) |
|-----------------------------|-------------------------------|
| 0.00                        | 0.00                          |
| 2.00                        | 2.03                          |
| 4.00                        | 3.99                          |
| 6.00                        | 6.04                          |
| 8.00                        | 8.02                          |
| 10.00                       | 9.99                          |
| 12.00                       | 12.01                         |
| 15.00                       | 15.01                         |

5. Conclusion
By using FBG to be optical filter, and processing the faint signals by DPSD, the characteristics of the gas difference absorption sensing system has been improved comparing the traditional system. The system has a number of advantages such as all-fiber sensor, high sensibility, simple construct and long distance measurement. If the step of keeping stable temperature of the environment is adapted, the precision and sensitivity will be advanced more.

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