TDLAS Based Early-stage Forest Fire Detection System

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Abstract— The commonly used forest fire detection methods are insufficient to detect the early-stage forest fire. In order to solve this problem, this paper presents a novel method to detect early-stage forest fire using TDLAS (Tunable Diode Laser Absorption Spectroscopy) technique. With the high sensitivity and rapid response, TDLAS is used to detect trace gas CO concentration sourcing from the early-stage forest fire. The TDLAS system is composed of a White-type multi-pass cell, combined with wavelength modulation and harmonic detection. The analysis of second-harmonic spectrum and the lab tests to different CO concentrations show that the relationship between CO concentration and spectrum intensity abide by linearity relations, and the system has high accuracy. It can be concluded that it is feasible to detect early-stage forest fire by measuring CO concentration and it interests to improve the system performance in the forest fire detection field.

1. INTRODUCTION

Forest fire will bring the most devastating consequences to the forest and the human life [1]. In our country, ground patrol and protect, watchtower monitoring [2], air patrol and protect and remote sensing satellites [3] are commonly used to detect forest fire. But all the above methods cannot detect the early fire effectively. The wireless temperature sensing technology [4] was proposed to improve the imperfections, but to no avail.

In order to improve the performance and sensitivity of forest fire detection system, this paper adopts a gas detection method with high detection sensitivity, which is the early detection of forest fire.

2. CHARACTERISTIC GAS IN EARLY FOREST FIRE

The forest fire has the specific physical and chemical characteristics process, which are outputted respectively in early stage, smoldering stage, heating stage and flame attenuation stage [5–7]. Gasses are mainly the product of the imperfect combustion in the early stage. In view of the produced gasses is earlier than temperature and flame, the early detection system detect gasses should be enough sensitive and rapid, then more easily to discovery the early detection of forest fire. So extracting characteristic signals of gasses in early forest fire has broad prospect [8].

The burning process will inevitably produce CO and CO_2. CO_2 is a kind of common gas with a certain concentration in atmospheric environment, but its concentration would rise sharply if the fire broke out. Usually it occurs in minute amounts for CO in the atmosphere and it is produced earlier than the CO_2 in the forest fire. CO is lighter than air and can rise and spread fast with little heat or without any heat, so it can be easily detected [9–11]. In a word, CO can be viewed as characteristic gas to detect is a rapid and accurate way in early forest fire.

So far, commonly used detection methods of gas concentration are mainly classified as chemical method, gas chromatography and spectral absorption method, but all methods are not ideal to detect trace gas detection. In recent years, due to it detects trace gas is rapid, real-time and highly sensitive, tunable diode laser absorption spectroscopy (TDLAS) has been widely applied in environmental, biomedical and industrial fields.

3. THE PRINCIPAL OF TDALS

In fact, TDLAS is a kind of absorption spectrum technology, using laser characteristics of narrow line width and wavelength tuning to scan the single absorption peak of the gas. It can obtain gas concentration by analyzing the spectral selective absorption. Beer-Lambert law is the theoretical basis of TDLAS [12, 13] technology. According to the law, the intensity of light beam will can be attenuated after gas molecules absorption to be

$$I_t(v) = I_0(v)\exp[-\alpha(v)CL] \tag{1}$$

whereas, $I_0(v)$ is incident light intensity, $I_t(v)$ is transmission light intensity after gas absorption, $\alpha(v)$ is absorption coefficient for unit concentration and unit length at frequency v, C is volume fraction, L is light path length.

4. SELECTION OF CO SPECTRAL ABSORPTION

The gas absorption spectrum can be obtained from HITRAN (2008) spectral database. The Absorption spectral line selection should consider both laser interference and background gas. It is shown from Figure 1 that CO has larger absorption spectrum strength at wavelength of about 1.58 µm. Around 1.58 µm, CO has higher spectral intensity than other gases and narrower wavelength than other domains, which is more suitable for TDLAS detection, as shown in Figure 2.

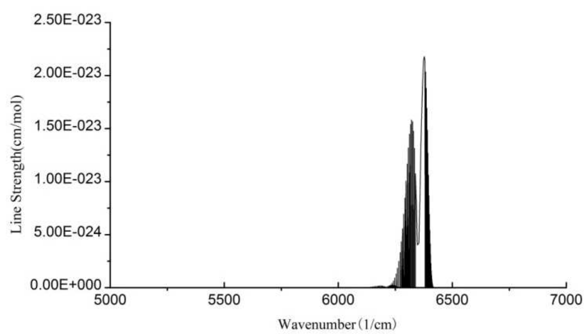


Figure 1: CO absorption spectral lines around 1.43 µm $\sim$ 2.0 µm.

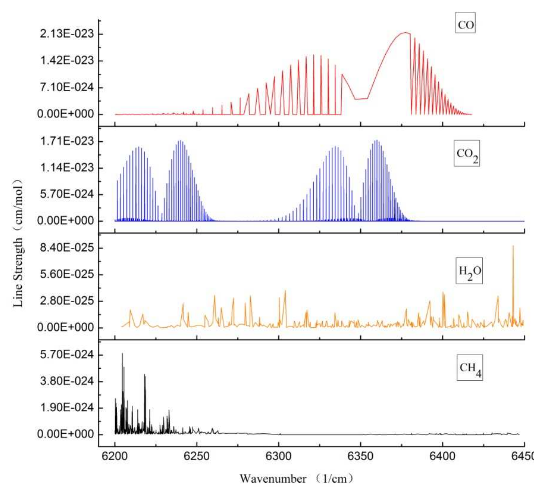


Figure 2: Absorption lines of common gases around 1.55 µm$\sim$ 1.61 µm.

5. BLOCK DIAGRAM OF THE DETECTION SYSTEM

For TDLAS based early forest fire detection system, its core part is the laser. Laser selection should consider several points: 1, the central frequency of the laser should match with the characteristics of gas absorption spectrum; 2, the price should relatively cheap and suitable for extensive application. In addition, due to Beer-Lambert law demands strictly monochromatic light, the light source should be selected distribution feedback (DFB) laser with the central wavelength distribution around 1.58 µm, narrow band width and high effective optical power, which helps to improve the system sensitivity.

The block diagram of TDLAS system is shown in Figure 3. The American Thorlabs ITC5000 controller is used to make the laser wavelength scan through the whole absorption lines by adjusting the injection laser current and temperature of the laser. The current is modulated by the external input modulation signal, and the modulation signal sent to the phase-locked amplifier as the reference signal. Laser driver drives the laser beam through the long optical path cell filled with gas. The light reaches the photoelectric detector after multiple reflections. After the weak light signal is multiplied and integrated by phase-locked amplifier and suppress noise, the useful harmonic signal is obtained. The harmonic signal is collected by the data acquisition card (DAQ card) send to computer processes and operates data, and then gas concentration is got.

This system adopts the structure of White absorption pool [14, 15]. The basic structure of the pool is shown in Figure 4(a). The absorption pool is mainly composed of three pieces of spherical mirrors; including primary mirror A, secondary mirror B and B'. All the mirrors have the same radius of curvature. Primary mirror is placed at one end of the absorption pool, and its center of curvature is in the middle of the secondary B and B'. The secondary B and B' is placed at the other side of the pool, and its curvature center is located on the primary mirror. Its entity structure is shown in Figure 4(b).

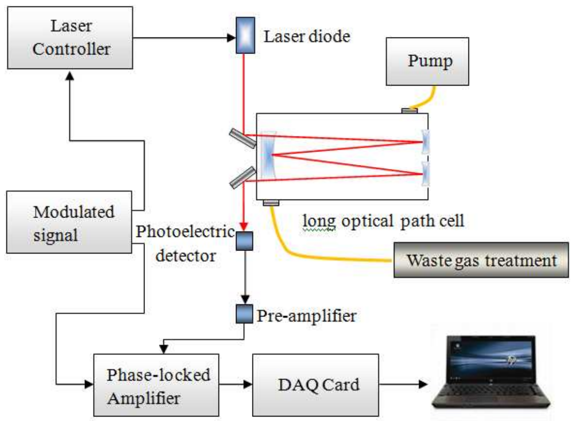
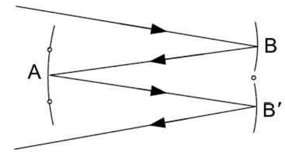
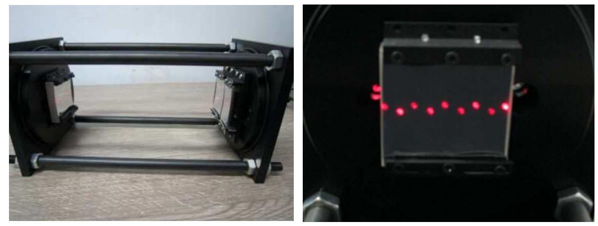


Figure 3: Block diagram of TDLAS system.



(a) The basic structure diagram



(b) Entity structure

Figure 4: The structure diagram and entity structure of the absorption pool spectrum.

6. RESULTS AND DISCUSSION

Due to the interference of the background gas, the direct absorption measurement technique and harmonic detection which have better measurement sensitivity and accuracy is adopted to measure of weak signal. With the increase of harmonics, the harmonic signal amplitude will decrease, so in the practical application first or second harmonic detection is generally chosen. It can be seen from Figure 5 that, in the line center, the second harmonic has relative high amplitude and the first harmonic is close to zero. Therefore, this paper uses the second harmonic peak to achieve concentration detection.

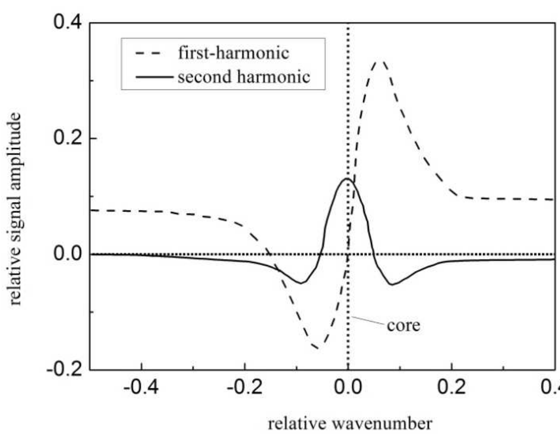


Figure 5: Second harmonic spectrum and first harmonic.

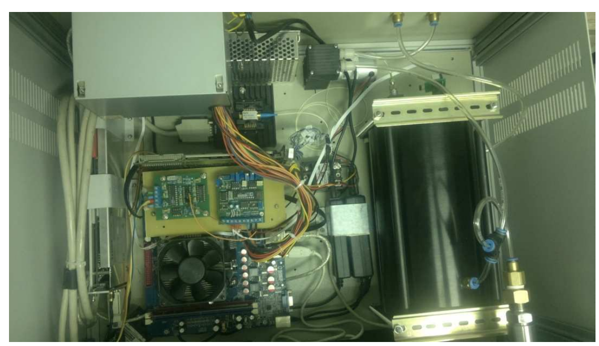


Figure 6: The picture of TDLAS detection system for early forest fire.

Referred to the existing literature [16–19] about TDLAS technology and the research progress of gas detection technology, the early forest fire CO gas detection system is designed and the picture is shown in Figure 6.

The laser frequency is adopted at 5 kHz for modulating the wavelength and the frequency is selected at 20 hz for scanning gas absorption peak. Selecting nitrogen as balance gas, CO gas was prepared with the volume fraction of 20 ppmv to165 ppmv The measurement result is shown in Figure 7. It can be seen that the second harmonic intensity changes with the concentration. From the linear fitting results shown in Figure 8, it can be demonstrated that the concentration of CO is in linear relation with the second harmonic intensity and the fitting result is $Y = 0.0251 + 0.00451X$.

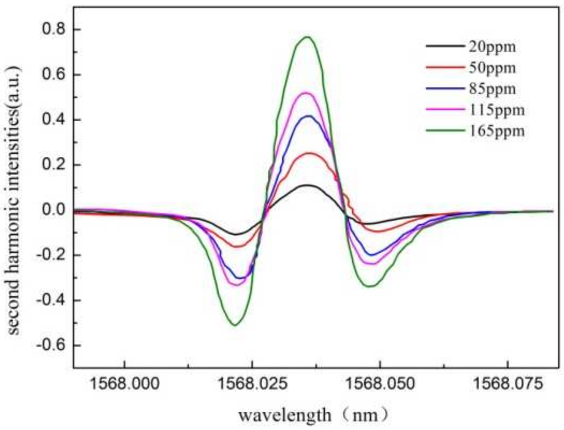


Figure 7: Second-harmonic spectrum for different CO concentrations.

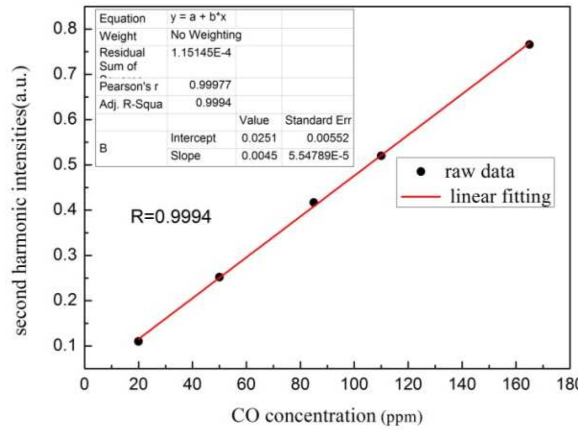


Figure 8: Relevance of CO concentration and second-harmonic spectrum intensity.

7. CONCLUDING REMARKS

For the trace gas detection, TDLAS technology has the advantages of high sensitivity, fast response speed, good selectivity and low detection limit, in several ppm levels. This will help to accurately detect the gas from the fire so as to realize the early detection of forest fires. It will be beneficial and meaningful to forest fire prevention and reduce the loss.

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