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Tunable fiber laser based photoacoustic gas sensor for early fire detection

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HIGHLIGHTS

- Photoacoustic multi-gas detection.
- Measurement and analysis H_2O, C_2H_2, CO and CO_2.
- The fire warning gases from smoldering paper were measured.

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ABSTRACT

A photoacoustic gas sensor using a near-infrared tunable fiber laser and based on wavelength modulation spectroscopy technique is developed. This sensor is capable of quasi-simultaneous quantification of water vapour, acetylene, carbon dioxide, and carbon monoxide (H_2O, C_2H_2, CO and CO_2) concentrations in the fire emulator. The feasibility of using this sensor as an early fire detector was demonstrated. The fire warning gases from smoldering paper were measured. The peak concentrations of gases from smoldering paper were 20,300 ppm H_2O, 2.1 ppm C_2H_2, 756 ppm CO, and 1612 ppm CO_2 after 400 s.

1. Introduction

The current generation of most fire sensors is designed to respond to the heat, smoke, or the electromagnetic radiation generated during smoldering and flaming combustion [1]. People have been trying to detect it in its early stages to give alarm and perform effective suppression. Some studies have shown that the chemical reactions during a fire produce many kinds of gaseous products some of which can be used as early fire detection [2,3]. These gases related to combustion processes which mainly apply for early fire detection are carbon monoxide (CO), carbon dioxide (CO_2), acetylene (C_2H_2), water (H_2O) and nitrogen oxides (NO*x*) [4]. In recent years, trace gas sensing techniques have been developed further and it has now become an area of major interest for fire detection [5].

Among many sensing techniques of trace gas, laser based photoacoustic spectroscopy (PAS) have been paid extensive attention by scientists due to its high resolution, rapid response, high sensitivity, multi-gas sensing and simple operation [6,7]. For example, Nebiker and Pleisch reported the applicability of the photoacoustic (PA) principle for the detection of combustion gases [4]. Chen et al. used the PA detection method to detect CO for fire warning [8]. However, an ideal sensor should also provide continuous data to allow monitoring of the growth of a fire and generate information specific gases. The near-IR tunable erbium-doped fiber laser based PA sensor has created new opportunity for early fire sensing, owing to its low cost and continuous detecting quality and multi-species trace gases detection.

In this paper, a PA gas sensor based on a near-IR tunable erbium-doped fiber laser (TEDFL) in combination with a fiber amplifier was designed and constructed. The performance of this sensor was demonstrated by the measurements of H_2O, C_2H_2, CO and CO_2 from smoldering paper.

2. Sensor configuration

The configuration of PA gas sensor is depicted in Fig. 1. The light source consists of a near-IR tunable erbium-doped fiber laser in

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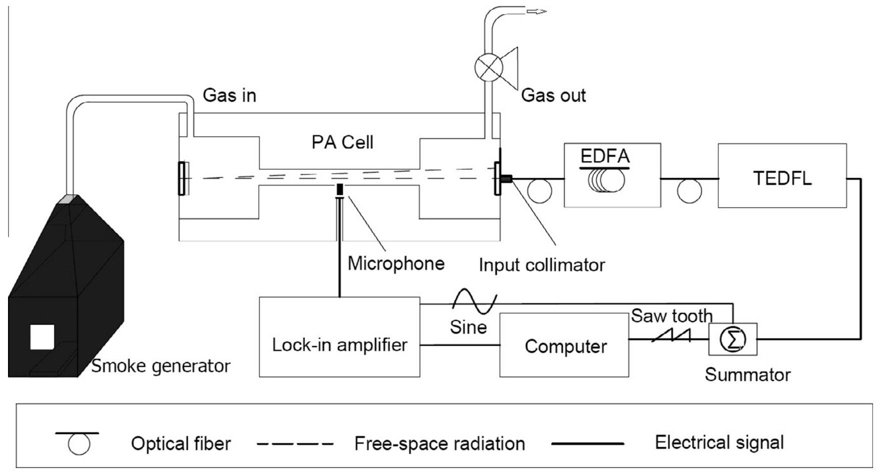

Fig. 1. Schematic representation of the PA sensor.

combination with an erbium-doper fiber amplifier (EDFA, Amonics, AEDFA-27-BFA). The TEDFL operates in continuous wave (CW) output power of greater than 6 mW to ensure that the EDFA is fully saturated. The output of the commercially available EDFA has up to 500 mW of CW output power with the same linewidth and wavelength as the TEDFL. The TEDFL is operated in wavelength modulation mode. The ramp voltage of different scan rate supplied by a DAQ (NI 6014) drives the laser to change the laser lines. The sinusoidal waveform voltage sent by the Lock-in Amplifier (Stanford Research Systems, SR830) dithers the laser's wavelength at half the resonant frequency of the PA cell. The operation wavelength of the TEDFL can be continuously scanned with different scan rate from 1520 nm to 1610 nm [7]. Wavelength modulated light from the TEDFL is amplified by the EDFA and coupled into the PA cell with a double-pass configuration through a fiber collimator.

The PA cell sealed with a quartz window and a gold coated mirror consists of a central cylindrical acoustic resonator (diameter = 10 mm, length = 100 mm) and two buffer volumes (length = 50 mm). For this cell, the resonant frequency of its first longitude mode is 1632 Hz and the Q-factor is about 26 at atmospheric pressure. The gas sampling pump controls target gas to enter the PA cell.

The smoke generator was built to measure the fire products. Fire emissions were sampled from a paper fire inside a small room with dimensions 0.2 m(L) × 0.2 m(W) × 0.3 m(H). The small room with a tray and a heating plate was made to be the work as a smoke generator. Fire products were sampled from the top position of the room by a gas sampling pump through a long pipe.

A sensitive microphone (Knowles EK3133, 22 mV/Pa) is placed in the middle of the PA cell resonator where the maximum of the acoustic wave occurs. An optimal modulation depth of 14 mV is determined for this PA sensor. For wavelength modulated PAS, the method to determine the optimum modulation amplitude has been described in the Refs. [7,9]. The PA signal is fed into the lock-in amplifier, and then transmitted to the computer where a computer program controls the data acquisition and processing.

3. Results

3.1. Absorption lines selection

In the region of 1520–1610 nm, there are numerous molecular species that exhibit ro-vibrational absorptions of overtone and combination bands, which allow trace gas detection by the contin-

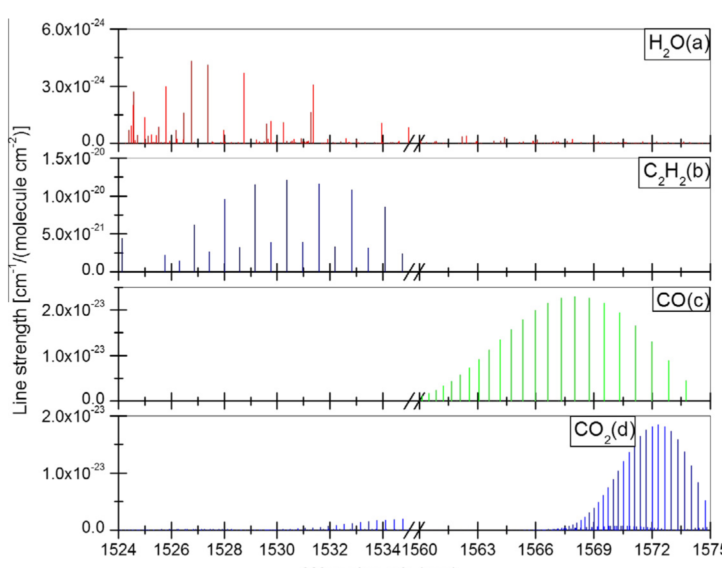

Fig. 2. Absorption spectrum of the gases (H_2O (a), C_2H_2 (b), CO (c) and CO_2 (d)) obtained from the HITRAN database.