Highly Sensitive H_2S Detection for SF_6 Decomposition Based on Photoacoustic Spectroscopy

Lei Dong[1], Xukun Yin[1], Hongpeng Wu[1], Frank K. Tittel[2]
[1]*State Key Laboratory of Quantum Optics and Quantum Optics Devices, Institute of Laser Spectroscopy, Shanxi University, Taiyuan 030006, China*
[2]*Department of Electrical and Computer Engineering, Rice University, Houston, Texas 77005, USA*
Author e-mail address: donglei@sxu.edu.cn

Abstract: A ppb-level hydrogen sulfide (H_2S) gas sensor for sulfur hexafluoride (SF_6) decomposition analysis was developed using photoacoustic spectroscopy technique and a watt-level excitation laser source. A minimum detection limit of 109 ppb was achieved.
OCIS codes: (280.3420) Laser sensors; (140.5965) Semiconductor lasers, quantum cascade; (300.6340) Spectroscopy, infrared.

1. Introduction

Sulfur hexafluoride (SF_6) gas has an excellent insulating property, which is widely used as an insulating medium in electric power systems, such as in gas-insulated switchgear (GIS), gas circuit breakers (GCBs), transformers (GIT) and transmission pipes (GIL) [1]. Normally, SF_6 is hard to decompose, but with successive reactions with contaminants such as water vapor and oxygen, various chemical byproducts, such as H_2S, SO_2, SF_4, CO, CF_4 and SOF_2 are generated, which can chemically attack solid insulation materials and accelerate insulation aging and eventually lead to power system failure. There is considerable interest in developing a sensitive, selective, and cost-effective sensor for H_2S detection in a SF_6 buffer gas environment, as it was recognized that the H_2S and SO_2 concentration levels can effectively determine the insulation condition of the electrical equipment [2, 3].

We report a photoacoustic spectroscopy (PAS) based sensor system for H_2S detection in SF_6 buffer gas [4]. A near-IR telecommunication diode laser was employed to reduce the cost and its power was boosted up to ~1.4 W by means of a low-cost, erbium-doped optical fiber amplifier (EDFA). A differential photoacoustic cell (PAC) was designed, which has a ~4 times higher quality factor for SF_6 than in N_2. As a result, a ppb-level SF_6 detection sensitivity was achieved.

2. Experimental setup and results

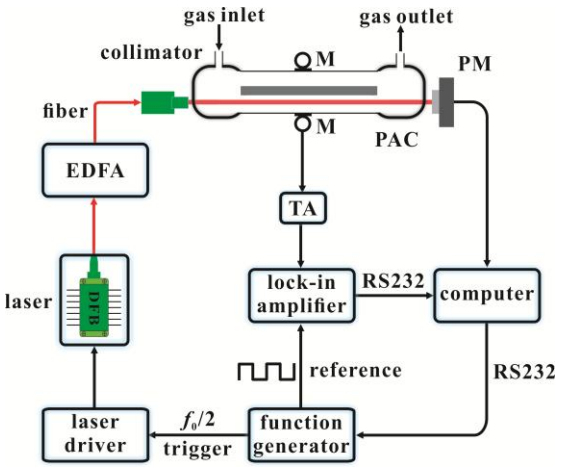

Fig. 1. Schematic of PAS based H_2S sensor system using a photoacoustic cell and a fiber amplified diode laser. EDFA: erbium-doped fiber amplifier; PAC: photoacoustic cell; PM: power meter; M: microphone and TA: transimpedance amplifier.

A schematic diagram of a PAS based H_2S sensor system is depicted in Fig. 1. A 20 mW telecommunication distributed feedback (DFB) laser (FITEL, model FRL 15DCWD) was used to reduce the sensor system cost. Its wavelength could be tuned from 1562 nm to 1582 nm. This laser was mounted onto a driver board, which controls both the DFB laser current and temperature. The current was modulated by a function generator (Agilent, model 33500B) at $f_0/2$, where f_0 is the resonant frequency of the PAC. The modulated laser beam was directed to an EDFA (Connect laser technology, model MFAS-L-EY-B-MP), which is used to boost the incident laser excitation power. The output laser beam from the EDFA with an output power of 1.36 W was directed to a fiber collimator (OZ optics,

model LPC-01) and then passed through a differential PAC. The PAC had two identical cylindrical resonators, each of which was 6×90 mm in size. Two electret condenser microphones were mounted on the walls in the middle of each resonator to detect the photoacoustic signals. The signals from the two microphones are differentially amplified. As a result, all noise components that are coherent in the two resonators and microphones, such as the flow, window noise and external electromagnetic disturbance are effectively suppressed and thus the signal-to-noise ratio (SNR) of the reported sensor system is increased. The differential signals were amplified by a transimpedance amplifier (TA) and then fed into a lock-in amplifier (Stanford research system, model SR830), which was used to demodulate the signals at 2*f* harmonics. The lock-in amplifier was set to a 1 s time constant and 12 dB/oct filter slope, corresponding to a detection bandwidth of 0.25 Hz.

A gas dilution system (Environics, model EN4000) was used to generate different concentrations of H_2S in N_2 or SF_6 buffer gas, respectively. A sampling system containing a diaphragm pump (KNF technology, model N813.5ANE), a pressure controller (ALICAT, model SL030) and a needle valve was used to control and maintain the sensor system pressure and gas flow. The gas flow rate was set at a constant value of 70 sccm for our experimental analysis.

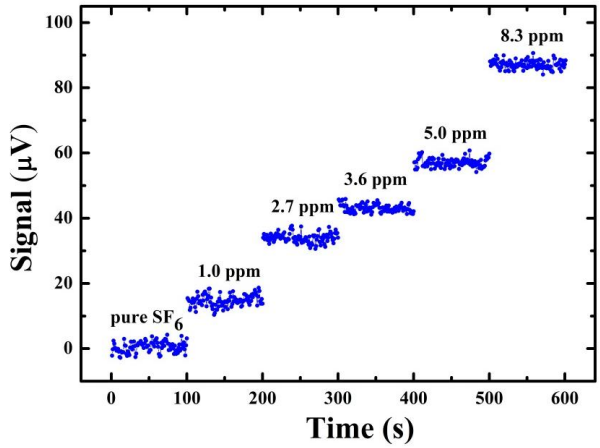

Fig. 2. Time sequence of concentration measurements for pure SF_6 and five different H_2S concentrations.

The interference-free H_2S absorption line at 6320.6 cm^{-1} was selected as the target line with a line strength of 1.056×10^{-22} cm/molecule. The laser temperature was set to 31.6 °C. A 2*f* wavelength-modulation spectroscopy (2*f*-WMS) technology was employed to obtain the H_2S photoacoustic signals ranging from 6320 cm^{-1} to 6322 cm^{-1} by scanning the laser current. Figure 2 shows the time sequence of the concentration measurements for pure SF_6 and five different H_2S concentrations. The signal amplitudes were recorded continuously for 100 seconds with the laser excitation wavelength locked at the center of the target H_2S absorption line. As shown in Fig. 2, a noise level of 1.6 μV was observed for pure SF_6. For a 1 ppm H_2S/SF_6 gas mixture, a mean signal of 14.7 μV was obtained and the SNR is 9.2. The minimum detection limit (1σ) for H_2S is 109 ppb for a 1 s averaging time, which corresponds to a normalized noise equivalent absorption (NNEA) coefficient of 2.9×10^{-9} $cm^{-1}WHz^{-1/2}$.

3. Conclusions

A ppb-level PAS H_2S sensor for SF_6 decomposition analysis was developed and demonstrated. The strength of the selected near-IR absorption line is ~10 times weaker than the absorption line in the mid-IR spectral regions, but was compensated by means of an erbium-doped optical fiber amplifier. The differential design of the PAC with a relative larger resonator diameter is capable of suppressing the noise and accommodates the high-power excitation source. These two factors work together and result in a minimum detection limit for H_2S of 109 ppb for a 1 s averaging time

4. References

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