

Ppb-level Detection of Acetylene based on QEPAS Using a Power Amplified Diode Laser

Yufei Ma^{1,*}, Yao Tong¹, Ying He¹, Xin Yu¹, Frank K. Tittel²

¹National Key Laboratory of Science and Technology on Tunable Laser, Harbin Institute of Technology, Harbin 150001, China

²Department of Electrical and Computer Engineering, Rice University, 6100 Main Street, Houston, Texas 77005, USA

E-mail address: mayufei@hit.edu.cn

Abstract: An ultra-high sensitive C₂H₂-QEPAS sensor using an EDFA amplified diode laser was demonstrated. The 33.2 ppb detection sensitivity verified that the design of the reported QEPAS method demonstrated significantly enhanced sensor performance.

OCIS codes: (280.4788) Optical sensing and sensors; (300.6260) Spectroscopy, diode lasers.

1. Introduction

Quartz-enhanced photoacoustic spectroscopy (QEPAS) technique is one of the most promising methods for trace gas sensing [1]. QEPAS has been applied to many trace gas detection applications due to its significant advantages such as high sensitivity, selectivity and compactness [2]. An important advantage of QEPAS is that the performance of QEPAS-based sensors can be improved if the excitation laser power is increased, since the QEPAS detection sensitivity scales linearly with excitation laser power. This feature differs from other laser absorption spectroscopy such as tunable diode laser absorption spectroscopy (TDLAS). Diode lasers are usually used in QEPAS based sensing systems due to their compactness and low cost. However, the output power of diode lasers is in the range of several milliwatts which limits the QEPAS detection performance. Erbium-doped fiber amplifiers (EDFAs) can realize significant optical signal amplification. An EDFA can be used to achieve an amplification gain of more than 30 dB when an appropriate seed diode laser is injected.

In this paper, an ultra-high sensitive acetylene (C₂H₂) QEPAS sensor was demonstrated. An EDFA amplified distributed feedback (DFB) diode laser which combines the merits of an EDFA and a diode laser emitting at 1.53 μm with superior output performance was used as the laser excitation source. A quartz tuning fork (QTF) with a low resonance frequency f_0 of 30.72 kHz was employed as an acoustic wave transducer.

2. Sensor architecture

A schematic of the QEPAS based sensor platform is shown in Fig. 1. An opto-isolator in the EDFA shown in Fig. 1 (a) was used to protect the DFB laser against back reflections. The output laser beam from the opto-isolator was collimated by using a fiber collimator (FC) and subsequently focused between the QTF prongs inside an acoustic detection module (ADM) by means of a plano-convex CaF₂ lens (L). The control electronics components required for modulation and demodulation are shown in Fig. 1 (b). When a seed laser with a 6.7 mW output at the absorption line, an EDFA amplified laser power of 1500 mW with a signal-to-noise ratio of ~ 30 dB was obtained.

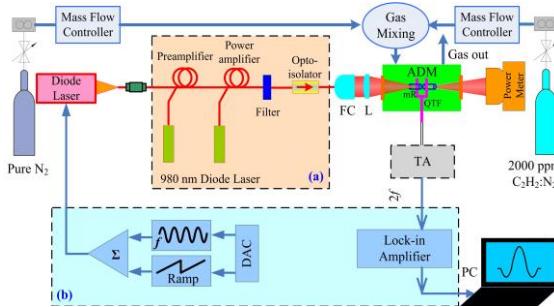


Fig. 1. Schematic of a C₂H₂-QEPAS sensor based on an EDFA amplified diode laser

3. QEPAS sensor performance

The QEPAS sensor performance was investigated using EDFA amplified DFB diode laser excitation. The optical power of the amplified diode laser increased from 100 mW to 1500 mW. The QEPAS sensor signal amplitude as a function of laser optical power is shown in Fig. 2. From Fig. 2, it can be seen that the QEPAS signal amplitude improved with increasing laser optical power and no saturable absorption effects were observed. This means that the C₂H₂-QEPAS signal amplitude can be even further improved when a higher power EDFA will be used.

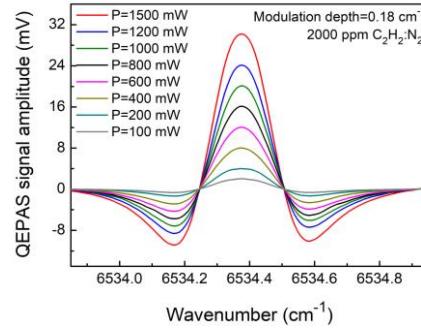


Fig. 2. $2f$ signal of the C_2H_2 -QEPAS sensor at a modulation depth of 0.18 cm^{-1} with different optical power levels

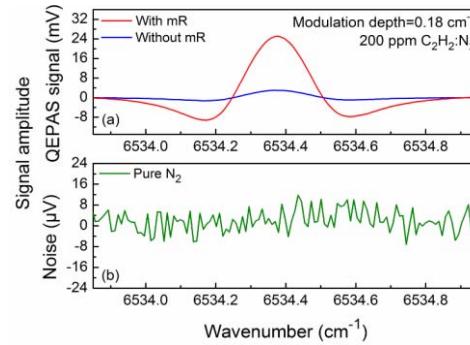


Fig. 3. Signal amplitude. (a) QEPAS signal with and without a mR. (b) Pure N_2 for a noise background determination.

A significant enhancement of the QEPAS signal can be achieved when two metallic tubes acting as a micro-resonator (mR) are added to the QTF sensor architecture. The length and inner diameter of stainless tubes were selected to be 4 mm and 0.5 mm, respectively, to constitute the mR. A 200 ppm $\text{C}_2\text{H}_2:\text{N}_2$ mixture was used to avoid signal saturation of the custom made lock-in amplifier. The measured $2f$ QEPAS signals with and without mR at a modulation depth of 0.18 cm^{-1} is shown in Fig. 3(a). The QEPAS signal was enhanced ~ 8 times as a result of the addition of the two mR tubes. Fig. 3(b) depicts the background signal measured when the ADM was flushed with ultra-high purity N_2 . The 1σ minimum detection limit (MDL) of the C_2H_2 -QEPAS sensor was 33.2 ppbv for a 1 sec time constant of the lock-in amplifier based on the data depicted in Fig. 3.

In conclusion, an ultra-high sensitive QEPAS based C_2H_2 sensor was demonstrated. An EDFA amplified diode laser with an output optical power up to 1500 mW was used as the QEPAS excitation source. A QTF with a low f_0 of 30.72 kHz was employed as an acoustic wave transducer. The high laser power and the low resonance frequency of QTF increase the QEPAS signal level. A significant further signal enhancement of 8 times was obtained when a mR was added to the QTF sensor architecture. For the C_2H_2 sensor, a 33.2 ppb MDL at 6534.37 cm^{-1} was achieved. The ppb-level detection sensitivity verified that the design of the reported QEPAS method demonstrated a significantly enhanced sensor system performance. The sensor capability can be further improved when an EDFA with even higher output power and a QTF with a lower f_0 are used [3].

Acknowledgements

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4. References

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