CW TEC DFB-QCL based sensor for ultra-sensitive detection of methane and nitrous oxide for environmental and medical applications

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Abstract: A sensitive and selective QEPAS-based sensor was developed for CH_4 (1275.04 cm^{-1}) and N_2O (1275.5 cm^{-1}) detection. Detection limits of 20 ppbv (CH_4) and 7 ppbv (N_2O) at 1σ were achieved with a 1-sec averaging time.

OCIS codes: (140.5965) Semiconductor lasers, quantum cascade; (300.6340) Spectroscopy, infrared; (280.4788) Optical sensing and sensors.

1. Introduction

The development and performance of a compact and portable sensor platform based on quartz-enhanced photoacoustic spectroscopy (QEPAS) [1-3] using a 7.83 μm continuous wave (CW), thermoelectrivally cooled (TEC), distributed feedback (DFB) quantum cascade laser (QCL) will be reported. The DFB-QCL frequency was selected to perform sensitive detection of CH_4 using an optimum line centered at 1275.04 cm^{-1}. Using the same QCL it was also possible to measure concentration levels of N_2O at 1275.5 cm^{-1}. The detection of CH_4 and N_2O has numerous real world applications, particularly in environmental monitoring and medical diagnostics. CH_4 and N_2O are next to CO_2 the most important greenhouse gases because of their global warming potential [4]. Furthermore, N_2O is a processing gas in electronics [5] and medicine [6, 7] as well as in aerospace applications [8, 9]. The detection of sub-ppb levels of N_2O can find application in medical diagnostics based on exhaled human breath analysis.

2. CH_4 and N_2O QEPAS sensor architecture: Experiments and Results

The CH_4 and N_2O QEPAS sensor architecture, as shown in Fig. 1, uses a CW, TEC 7.83 μm DFB QCL (AdTech Optics, HHL 12-25), capable of a maximum output power of ~ 300 mW. A QCL beam collection, propagation and focusing is accomplished by means of germanium (Ge) (f=40 mm) and zinc selenide (ZnSe) (f=25 mm) plano-convex lenses and a 200 μm pinhole for spatial filtering. The acoustic detection module (ADM) consists of a quartz tuning fork (QTF), an acoustic micro-resonator (mR) and a closely located low-noise preamplifier [9]. The optimized mR consists of two hypodermic tubes [10], 4.0 mm long with 0.8 mm inner diameter, mounted on both sides of the QTF. The 7.83μm DFB-QCL was operated at 21.5°C and its injected current was varied between 430 and 500 mA in order to detect the selected CH_4 and N_2O absorption lines at 100 Torr.

The presence of CH_4 and N_2O in ambient laboratory air was detected by the QEPAS sensor using wavelength modulation spectroscopy with *2f* detection (blue plot of Fig. 2). Furthermore, the *2f* signal of a calibrated mixture of 1.8 ppmv N_2O in N_2 (red plot) is also depicted in Fig. 2. In order to enhance the QEPAS signal amplitude, a controlled amount of water vapor was added to enhance the V-T relaxation processes of the target gases. By comparing the QEPAS signal amplitudes for both N_2O measurements at 1275.5 cm^{-1}, we deduced the ambient laboratory N_2O concentration to be 393 ppbv. The minimum detectable concentration (MDC) for targeted N_2O and CH_4 absorption lines was calculated to be 7 ppbv and 20 ppbv, respectively for a 1 sec data acquisition time. In addition long term, sensitive atmospheric concentration measurements of CH_4 and N_2O using an absorption line locking mode were performed since their natural abundance in the atmosphere is ~1.8 ppmv and ~320 ppbv, respectively. Currently, the development of a compact optical platform, shown in Fig. 3 is in progress. The dimension of the QEPAS sensor will be optimized in order to achieve a compact, portable sensor system for the detection of CH_4 and N_2O.

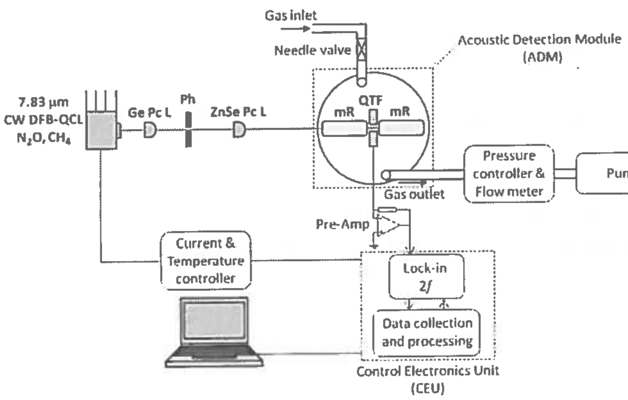

Figure 1: Ge Pc L and ZnSe Pc L – plano-convex lenses, Ph – pinhole, QTF – quartz tuning fork, mR – acoustic micro-resonator

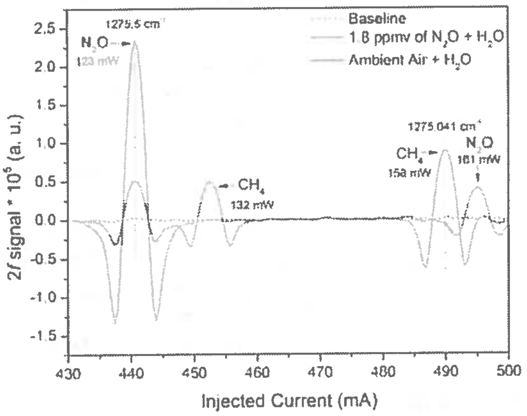

Figure 2: 2*f* QEPAS signals for a moisturized 1.8 ppmv mixture of N_2O in N_2 (red plot) and for CH_4 and N_2O in ambient laboratory air (blue plot). The dotted curve represents the optical sensor baseline. Total gas pressure for both QEPAS signal scans was P=100 Torr.

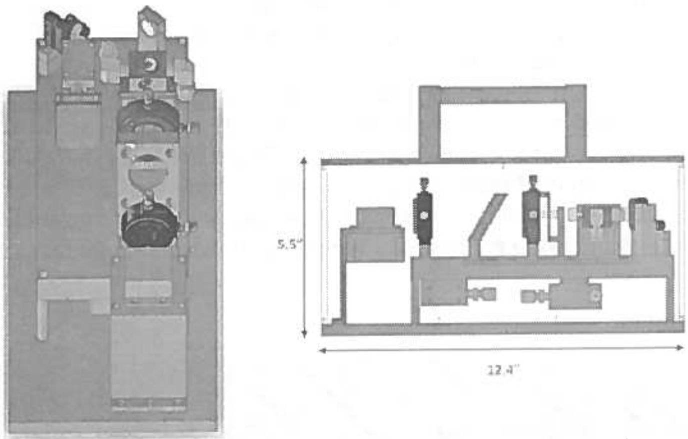

Figure 3: Design of a compact, robust sensor for CH_4 and N_2O detection

3. References

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