Carbon monoxide detection using a high power CW 4.6 µm DFB Quantum Cascade Laser based QEPAS sensor

R. Lewicki*[a], Y.F. Ma[a], M. Jahjah[a], M. Razeghi[b] F. K. Tittel[a]
[a]Rice University, 6100 Main St., Houston, TX, 77005
[b]Northwestern University, 2220 Campus Drive, Evanston, IL 60208

BIOGRAPHY

Rafal Lewicki received his M.S. and Ph.D. degree (cum laude) in Electronics from Wroclaw University of Technology, Wroclaw, Poland in 2005 and 2011, respectively. In December 2005, he joined the Laser Science Group at Rice University, Houston TX as a visiting scholar and currently he is holding a Postdoctoral Research Associate position in the Department of Electrical and Computer Engineering at Rice University. His research interest is focused on trace gas detection using laser based spectroscopic techniques. His current activities is the implementation of quantum cascade laser based sensor platforms, enabling high resolution, selective and real time spectroscopic measurements for applications in environmental monitoring, medical diagnostics, and industrial process control.

TECHNICAL ABSTRACT

Carbon monoxide (CO) is recognized as a major air pollutant which plays an important role in the atmospheric chemistry due to its impact on troposphere ozone formation and indirect effect on global warming by reducing the abundance of hydroxyl radicals [1]. The major sources of CO emission into the atmosphere result from the incomplete burning of natural gas and other carbon containing fuels that are widely used for power generation, petrochemical refining as well as automobile and truck transportation. The availability of a compact CO sensor with ppbv-level detection sensitivity and fast response will allow effective monitoring and quantification of CO urban and industrial emissions. Furthermore, an elevated CO concentration levels in exhaled breath are associated with asthma, diabetes, and hemolytic diseases [2]. Therefore, ultra-sensitive CO detection is also a promising tool for non-invasive medical diagnostics.

Quartz enhanced photoacoustic spectroscopy (QEPAS) is a sensitive technique that allows performing measurement of trace gases in an ultra small absorption detection module (ADM) where the total volume of the analyzed gas sample is ~4 mm^3 [3]. The QEPAS technique employs a 32 kHz quartz tuning fork (QTF) as a sharply resonant acoustic transducer, instead of a broadband electric microphone used in conventional photoacoustic spectroscopy. The QTF is a piezo-electric element, capable of detecting weak acoustic waves generated when the modulated optical radiation interacts with a trace gas, and converting its deformation into a separation of electrical charges. An 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. A recent optimization study of the geometrical mR parameters showed that the highest QEPAS signal-to-noise ratio (SNR) is achieved for two 4.4 mm-long and 0.5-0.6 mm inner diameter tubes [4]. However for a typical QCL beam, short mR tubes with a larger inner diameter are advantageous in facilitating the optical alignment of the QCL excitation beam with the respect to the mR and the QTF. Therefore for the DFB-QCL based CO QEPAS measurements a length and an inner diameter of the mR tubes of 4.0 mm and 0.84 mm, respectively were selected. Furthermore, an additional enhancement of the CO QEPAS signal amplitude was achieved by blending an analyzed mixture with water vapor, which is known to be an efficient catalyst for V-T relaxation in the gas phase.

A prototype CO QEPAS-based platform is using high power room temperature, continuous wave (CW) 4.6 µm distributed feedback quantum cascade laser (DFB-QCL) from Northwestern University. The DFB-QCL beam was collimated using black diamond AR coated aspheric lens with a 1.7 mm effective focal length. An optical power emitted by the laser at 1200 mA is 1W at an operating temperature of 10 °C (see Fig. 1a). This laser was designed to target the R5 and R6 CO absorption lines of the CO fundamental band at the 2165.6 cm^{-1} and 2169.2 cm^{-1}, respectively (see Fig. 1 b). For sensitive CO concentration measurements a 2f wavelength-modulation (WM) technique was used. The DFB-QCL current and temperature were set and controlled by ILX Lightwave current source (model LDX 3220) and

Wavelength Electronics temperature controller (model LFI 3751), respectively. Modulation of the laser current at half of the QTF resonance frequency (f_{mod}=16.38 kHz) was performed by a custom control electronics unit.

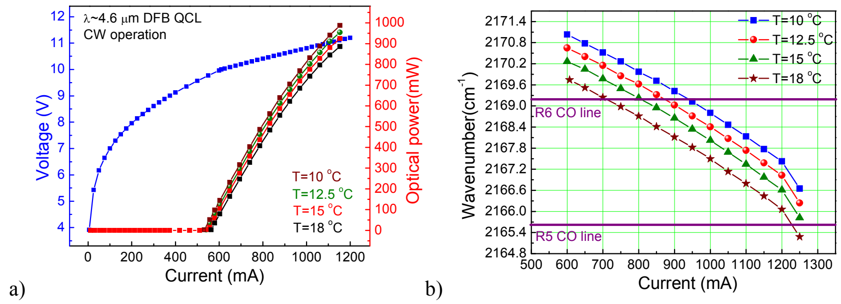

Fig. 1 (a) LIV curve of the 4.6 µm room temperature, CW, DFB-QCL from Northwestern University (b) DFB-QCL current tuning at different QCL operating temperatures.

In order to improve the quality of the QCL beam two 25 mm and 20 mm focal length plano-convex CaF_2 lenses and a 200 µm pinhole are used as a spatial filter. The second lens is used to direct the laser radiation through the mR and between the prongs of QTF mounted inside the ADM with a transmission efficiency of >93%.

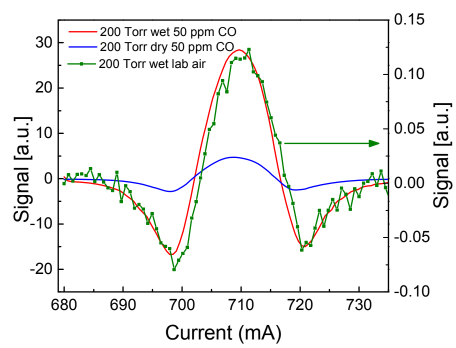

Fig. 2 The 2f QEPAS spectra of the R6 CO absorption line centered at 2169.2 cm^{-1} for a dry and moisturized 50 ppmv $CO:N_2$ mixture and for moisturized ambient laboratory air (green plot).

All the quantitative CO measurements were performed in a scan mode at a gas pressure of 200 Torr which according to previous experimental results is within the optimal pressure range for QEPAS based CO detection [5]. The 2f QEPAS spectra of the R6 CO absorption line centered at 2169.2 cm^{-1} for a dry and moisturized 50 ppmv $CO:N_2$ mixture and for moisturized ambient laboratory air is depicted in Fig. 2. The addition of 2.2 % water results in a 6 times signal enhancement, which confirmed that the presence of water can significantly improve the CO V-T relaxation rate. For a 50 ppmv $CO:N_2$ certified mixture and 2.2 % water vapor concentration the calculated noise-equivalent concentration of CO with a 1s averaging time is ~10 ppbv (1σ).

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