

# Multi-species Trace Gas Analysis with Dual-wavelength DFB-QCLs

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**Abstract:** We evaluate two designs of dual-wavelength DFB-QCLs for high-resolution multi-species laser absorption spectrometers. Several room-temperature dual-wavelength QCLs were combined to measure concentrations of the most important pollutants and greenhouse gases in a compact laser spectrometer with state-of-the-art precision.

**OCIS codes:** (280.1120) Air pollution monitoring; (300.1030) Absorption spectroscopy; (140.5965) Semiconductor lasers, quantum cascade

## 1. Introduction

Infrared absorption spectroscopy is a highly selective, precise and versatile method for trace gas monitoring of pollutants and greenhouse gases. Additionally, laser spectroscopy offers the possibility of measuring many species with the same method. Hence, dual-wavelength continuous wave (cw) DFB-QCLs are beneficial light sources for compact multi-species laser absorption spectrometers for environmental monitoring, industrial applications and medical breath analysis. Simultaneous emission of two wavelengths in one QCL at cryogenic temperatures was first demonstrated by Straub *et al.* [1]. Later, QCLs with capability to measure NO and NO<sub>2</sub> in pulsed mode were developed [2]. These twin DFB-QCLs have two DFB sections above one ridge and emit two wavelengths from a single facet. Recently, their suitability for simultaneous detection of CO, N<sub>2</sub>O and CO<sub>2</sub> was demonstrated [3]. In this work, two dual-wavelength DFB-QCLs are combined to measure six species and the necessary driving and data acquisition schemes are discussed. By adding a third dual-wavelength QCL we anticipate the feasibility of a single spectrometer with combined laser outputs that cover the vast majority of pollutants and greenhouse gases in today's monitoring networks.

## 2. Dual-wavelength DFB-QCLs

We demonstrate the suitability of anti-reflection coated twin DFB-QCLs for high precision multi-trace gas analysis by driving the laser in intermittent continuous wave (icw) mode [4]. These lasers operate close to room-temperature without the need for additional water cooling, which makes them very attractive for application in mobile instruments.

Furthermore, an alternative concept for dual-wavelength QCLs will be presented. In this approach, two DFB-QCLs are fabricated next to each other, separated by a few tens of micro-meters still allowing for collimation in a single beam (Figure 1). These neighbouring QCLs do not suffer from internal etaloning that is inherent to twin QCLs [3]. As opposed to the concept of QCL arrays [5] these devices are precisely designed for specific wavelengths and can be driven in icw mode to rapidly tune with high resolution over a spectral absorption feature of interest.

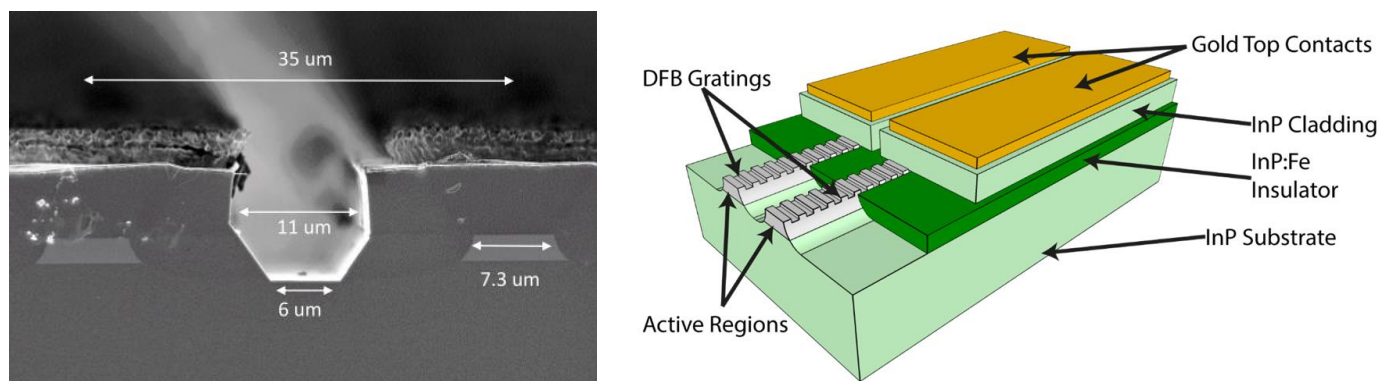


Figure 1: Left: SEM picture of a neighbour DFB-QCL. Right: Illustrative representation. The laser is designed to emit at exactly  $1600\text{ cm}^{-1}$  and  $1900\text{ cm}^{-1}$  to measure concentrations of the pollutants NO and NO<sub>2</sub>.

### 3. Trace Gas Analysis

Using such mid infrared dual DFB-QCLs in combination with a long-path absorption cell allows us to measure the concentration of several species in a gas sample. For example, the atmospherically highly relevant species CO<sub>2</sub> (both <sup>12</sup>CO<sub>2</sub> and <sup>13</sup>CO<sub>2</sub>), CO and N<sub>2</sub>O were simultaneously measured with a precision of 0.16 ppm, 0.22 ppb and 0.26 ppb using 1 s integration time and an optical path-length of 36 m. The Allan-variance minimum is reached after 100 s integration time and corresponds to precisions of 20 ppt (CO), 30 ppt (N<sub>2</sub>O) and 40 ppb (CO<sub>2</sub>).

The lasers are driven time-multiplexed in icw mode sharing a single detector and the spectra of each QCL are recorded by an FPGA based data acquisition system with a sampling rate of 125 MS/s and 14 bit resolution. The FPGA system is suitable to provide the full control of the spectrometer: It triggers the laser pulses and records the spectroscopic data in real-time. Additionally, it operates digital in- and outputs to control gas-valves and other peripheral devices. Averaged spectra are transferred to a PC where a LabVIEW based program is used to analyze the absorption data and determine the gas concentrations.

In summary, we will show how several dual-wavelength QCLs can be combined to measure concentrations of the most important pollutants and greenhouse gases with state-of-the-art precision in a single compact instrument.

### 4. References and Acknowledgements

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