Novel gas cell design for CO₂ isotopic composition measurements using mid-infrared laser absorption spectroscopy

Markus Mangold*, Bela Tuzson*, Herbert Looserb, Lukas Emmeneggera
a Empa, Swiss Federal Laboratories for Materials Testing and Research, Laboratory for Air Pollution and Environmental Technology, Überlandstr. 129, 8600 Dübendorf, Switzerland;
b FHNW, University of Applied Sciences, Institute for Aerosol and Sensor Technology, Klosterzelgstrasse 2, 5210 Windisch, Switzerland.

BIOGRAPHY

Markus Mangold: Markus Mangold (* 01. 31. 1981) has studied Nanotechnology at the University of Basel, Switzerland, from where he graduated in 2007. He obtained the degree as a Master of Science for his studies on the electrical conductance of organic molecules incorporated in gold nanoparticle networks. Markus continued his education at the “Technische Universität München”, Germany. During his PhD he studied the optoelectronic properties of gold nanoparticle arrays and electrically contacted organic molecules. In his thesis entitled “Gold Nanoparticle Arrays – a Platform for Molecular Optoelectronics” he demonstrated the use of single organic molecules as photodetectors.

Recently, Markus Mangold turned to mid-infrared spectroscopy. As a post-doctoral fellow at Empa, the Swiss Federal Laboratories for Materials Testing and Research, he develops a gas sensing platform, suitable for trace gases, including high-precision CO₂ isotope ratio measurements. His main interests include new developments in the field of mid-infrared lasers and detectors, novel gas cells, and the combination of these elements to create highly sensitive and selective absorption spectrometers.

TECHNICAL ABSTRACT

Mid-infrared (MIR) laser spectroscopy is widely used to monitor trace gas species in industrial, medical, and environmental applications. Also known as the spectral fingerprint region, MIR is especially attractive because it contains the strong fundamental ro-vibrational bands. Especially in combination with room temperature, continuous wave quantum cascade lasers, MIR laser spectroscopy allows for excellent selectivity, sensitivity, and precision.

The mixing ratio of CO₂ isotopes is of great interest for diverse applications ranging from cancer detection to climate research. In earlier studies, we have successfully demonstrated CO₂ isotope ratio measurements with a precision exceeding 0.1 ‰ and suitable for long-term remote measurements. In a recent work, we have introduced a compact gas cell consisting of six individually adjustable spherical mirrors, forming a two dimensional resonator with a star-shaped beam-pattern.

Here, we present a new design of a gas cell employed for MIR laser spectroscopy. It consists of a diamond turned 80 mm diameter copper cylinder. The cylinder has a single window serving as entrance and exit aperture for the light beam. In the plane of the light beam, a toroidal mirror is carved into the cylinder surface. At each reflection from the toroidal surface, the light beam is refocalized. This leads to minimal aberration of the laser beam after multiple reflections. The top part of Figure 1 shows a simulation of the light path in the toroidal cell. Below the simulation, a photograph shows the experimental realization of the beam pattern. Thanks to the planar light distribution in the cell, a small detection volume combined with a robust and easy optical alignment is obtained. In the current configuration, we

*markus.mangold@empa.ch; phone +41 58 765 4073; empa.ch

Fig. 1: FRED®-simulation (top) and photograph (bottom) of the light pattern in the toroidal gas cell.
achieve an optical path of 2.3 m in a sample volume of less than 40 ml. The excellent path to volume ratio leads to a fast response to changes in the gas composition. Furthermore, the cell body and the mirrors are formed from one piece. Therefore, the cell is very robust and it can be produced at low costs.

In combination with the cell, we use a continuous wave quantum cascade laser (QCL) emitting at 2310 cm⁻¹. In this spectral region, the concentrations of the four most abundant, stable CO₂ isotopes can be analyzed in one measurement. Figure 2 shows an experimentally obtained absorption spectrum. The light detection in our instrument is based on a quantum cascade detector (QCD). The spectrally narrow QCD allows for MIR detection with a very low background signal. To complement the setup, a fast data acquisition and processing was developed, allowing for 1 kHz real time data rates. Using the novel gas cell design and the QCD, we present real time, high-precision monitoring of the isotope composition of CO₂ at ambient concentration.

References


Keywords: absorption spectroscopy, CO₂ isotopes, gas cell, quantum cascade detector