Sulfur dioxide detection using 7.4 µm DFB-QCL based cavity enhanced absorption spectroscopy

*[1,2]J. Tarka, [1,2]P. Stefański, [1]R. Lewicki, [3]S. So, [1]M. Jahjah , and [1]F. K. Tittel

[1]*Rice University, Electrical & Computer Engineering Department, MS-366; 6100 Main St. Houston, TX, 77005*
[2]*Laser and Fiber Electronics, Institute of Telecommunications & Acoustics, Wroclaw University of Technology, Wroclaw, 50-370, Poland*
[3]*Sentinel Photonics Inc.,STE 208, 11 Deer Park Dr, Monmouth Junction, NJ, 08852*
*jan.tarka@rice.edu

Abstract: A quantitative measurements of sulfur dioxide using CW, RT DFB-QCL based cavity-enhanced absorption spectroscopy and 2f wavelength modulation detection technique will be reported. Detection limits of 130ppbv (1σ) were achieved with a 0.4-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 of a sensitive, selective and compact sensor platform, capable of detecting and monitoring sulfur dioxide (SO_2) at ppbv concentration levels will be reported. SO_2 has been identified by the United States Environmental Protection Agency (US EPA) as one of six "critical pollutants", for which emission levels should be monitored in order to protect the environment as well as public health. The main sources of SO_2 emission into atmosphere are related to industrial combustion processes and all types of transportation. Moreover when SO_2 reacts with water in the atmosphere it leads to acid rain [1].

A tunable laser absorption spectroscopy (TLAS) [2], especially combined with cavity enhancement (CEAS) and wavelength modulation spectroscopy (WMS), is the method of choice to provide highly sensitive detection and quantification of many important trace gas species. Optical trace gas sensors using TLAS as a spectroscopic technique are capable of reliable operation. In this work a TLAS technique was employed to target the 1344.45 cm^{-1} absorption line from the strong fundamental vibration-rotation band of SO_2 to achieve detection limit for SO_2 at ppb concentration levels.

2. Experimental Setup for SO_2 detection

A SO_2 sensor platform employing a 7.44 µm continuous wave (CW), room temperature, and thermoelectrically cooled (TEC) distributed feedback (DFB) quantum cascade laser (*Alpes Lasers SA)* as the spectroscopic excitation source is depicted in Fig. 1. This DFB-QCL laser, mounted in a high heat load (HHL) package, is driven by a commercially available laser current source (ILX Lightwave LDX-3232) and controlled externally by a compact state-of-the-art surface mounted electronic control board (*Sentinel Photonics Inc*.) which also performs the data acquisition process.

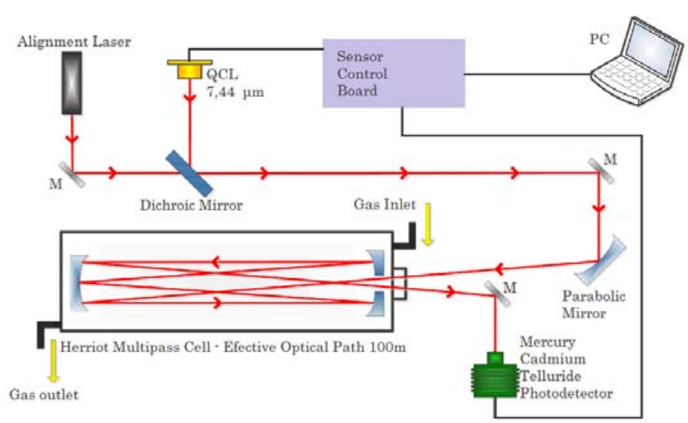

Fig. 1: Schematic of SO_2 gas sensor using a 7.44 µm DFB –QCL as the excitation source, M- mirror

Alignment of the mid-infrared SO_2 sensor system was performed with a red laser diode that was used as a tracking beam by combining the QCL beam with a dichroic, gold mirror from ISO Optics BSP-DI-25-3. Both beams are injected into the 100 m effective optical length, astigmatic Herriott cell (*Aerodyne Research Inc*) with the help of a parabolic mirror which focuses the beams in the center of the Herriott cell. The QCL output beam is directed to a liquid nitrogen cooled Mercury Cadmium Telluride (MCT) photo-detector (*Kolmar Technologies* KMPV8-1-J1/DC) with 8 µm cutoff wavelength. During 2f wavelength modulation measurements, the data are sampled synchronously via an embedded analog-to-digital converter and characteristic absorption spectra are produced by a digital lock-in amplifier algorithm. The control board can also synchronously apply a continuous saw-tooth current ramping at 8 Hz which is the 32-bit lock-in amplifier signal.

3. SO_2 sensor performance

The targeted SO_2 line located at 1344.4 cm^{-1} is obtained by setting the DFB-QCL temperature and current to 14°C and 750 mA, respectively. Wavelength scanning across the SO_2 absorption line is performed using a 8Hz saw-tooth current ramp. A modulation sine wave at 16 kHz and with 12 mA amplitude delivered by the sensor control board was superimposed on the current ramp. The gas pressure inside the multipass cell is maintained by MKS pressure controller at 200 Torr in order to eliminate water interference on targeted SO2 absorption line.

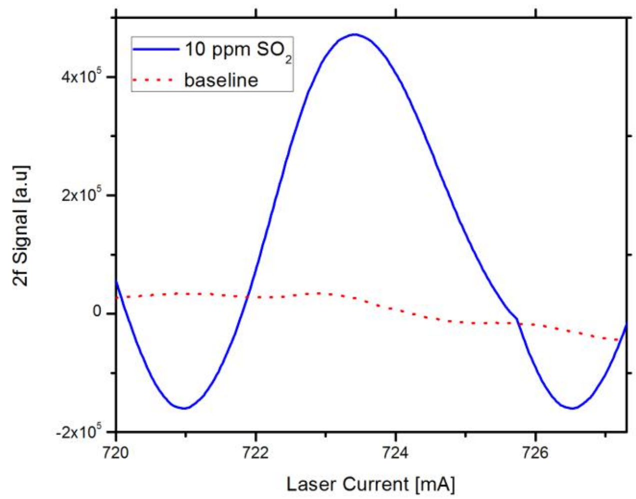

Fig. 2: 2f sensor signal for moisturized 10 ppm mixture of SO_2 and N_2(blue plot), dotted curve represents optical sensor baseline. Total gas pressure for scan was 200 Torr

Based on preliminary results shown in Fig. 2 a 1σ minimum detection limit (MDL) for the targeted SO_2 line was 130 ppb with a 0.4 second averaging time. This result exceeds the recently reported MDL value in ref. 4. The MDL value obtained to date may be further improved by using longer averaging times and suppressing baseline fluctuations. Experimental results for SO_2 detection achieved after locking the laser frequency to center of the absorption line will be also reported. The use of novel and ultra-sensitive detectors (e.g. quantum cascade detectors) as well as improving the data acquisition methods will enhance the use of mid-infrared QCL based SO_2 sensor systems in real world applications.

4. References

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