Compact Gas Sensors Based on Pulsed Quantum Cascade Lasers for Industrial Applications

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Sensitive, compact devices for trace gas monitoring are required for a number of applications that include industrial process control, environmental monitoring, and non-invasive medical diagnostics. A well-established technique for detecting molecular species in the gas phase is high-resolution infrared absorption spectroscopy. Fundamental vibrational absorption bands of molecular species are located in mid-IR region (3 to 20 μm). Quantum cascade (QC) lasers are the only kind of semiconductor lasers that enable to reach this region without the use of cryogenic cooling. When a distributed feedback (DFB) structure is embedded into such a device, it operates in a single-frequency mode, which is essential for spectroscopic applications. QC-DFB lasers operate at near-room temperature (with thermoelectric cooling) only in a pulsed low-duty cycle mode. This mode of operation leads to a relatively broad (~300 MHz) and asymmetric laser line. Such device characteristics require the development of new approaches to measurement procedures, data acquisition and analysis compared to those developed for conventional diode laser spectroscopy.

The QC-DFB laser based gas sensor architecture is defined by the required sensitivity for a particular gas species. A single channel sensor configuration was used to detect ammonia by its absorption in the ν2 vibrational band ($\lambda \approx 10$ μm)[1]. The sensitivity of this sensor was ultimately limited by pulse-to-pulse fluctuations of the QC-DFB laser energy. The QC-DFB laser was mounted on top of a three-stage thermo-electric cooling element inside a vacuum-tight housing with overall dimensions of 100×160×180 mm3 assembled from commercially available vacuum and opto-mechanical components. To remove the heat generated by the operation of the Peltier cooler, the bottom of the thermo-electric assembly was soldered to a water-cooled housing base plate. A temperature controller was used to set and monitor the laser temperature. With this arrangement, the operating QC-DFB laser could be cooled to -55°C.

The laser emission was collimated using an aspheric AR coated ZnSe lens with a focal length of 3 mm and a diameter of 6 mm mounted inside the housing. The collimated laser light emerged from the housing through a 30' wedged AR coated ZnSe window for 10 μm radiation and was directed to a 1 m long optical gas cell. To detect NH3, the absorption lines aR1(2) at 992.4503 cm-1 and aR0(2) at 992.6988 cm-1 in the ν2 fundamental absorption band were selected. These lines are strong, well resolved at pressures below 200 Torr and free from interference due to absorption by water and other air components. The pulsed QC-DFB laser available for this work accessed the targeted NH3 absorption lines when operated at a temperature of –11.7°C. A sensitivity of better than 0.3 ppmv was achieved with an effective 1 m optical pathlength. To further improve the QC-DFB laser based gas sensor performance, we plan