Brief description of chemical compound monitoring by high-precision absorption spectroscopy using quantum cascade lasers

Technology

For the monitoring of chemical compounds in gaseous media laser absorption spectroscopy (LAS) uses the property of molecules to absorb electromagnetic radiation of certain wavelengths. Therefore the laser light is sent through the medium which has to be analysed. By detecting the strength and position of absorptions the type and concentration of the present substances can be determined very fast (up to ns scale) with high precision (up to ppt level).
Quantum cascade lasers (QCL) are favourable radiation sources for LAS in the mid-infrared spectral range (3-20 µm) because they operate at room temperature and allow the design of compact robust instruments for industrial applications. The mid-infrared spectral range is of great advantage over the visible and near-infrared ranges, because many molecules have much stronger absorption and several chemical species absorb exclusively here. Therefore lowest substance concentrations up to ppt level can be detected.

Measurable substances

Generally, with one laser it is possible to measure one selected chemical species. If however there are two interesting molecules, whose absorption lines are close to each other, both can be monitored with a single laser. The detection of higher numbers of chemical compounds is possible by using several lasers at different spectral positions simultaneously. Please note, that symmetric molecules as e.g. H_2 or O_2 are not detectable in the mid-infrared spectral range. In the attached Table 1-1 examples of some measurable species and their detection limits are shown.

Key benefits

- self-calibrating through continuous measurement of irradiated and transmitted laser light
- high selectivity by identifying distinct absorption lines of the chemical species
- very high detection sensitivity up to parts per trillion (ppt)
- rapid results with high time resolution up to the nanosecond (ns) range
- easy handling as lasers and detectors need no LN_2 cooling
- no interference / distortion of the measured medium or the process to be monitored
- simultaneous measurement of several molecules by using multiple laser systems

Product families and typical applications

- Q-MACS [1] Process
    - process analysis and control
    - in-situ measurement within the process environment
    - coupling of the laser beam via open path guidance or fibre optics
    - plasma etching processes (e.g. semiconductor and photovoltaic industry, surface treatment)
    - sintering processes (e.g. control of industrial furnaces)

- Q-MACS Trace
    - trace gas analysis
    - ex-situ measurement in long path cell
    - feeding of the measuring sample into the long path cell
    - determination of gas purity (e.g. chemical industry)
    - flue gas measurement (e.g. waste incineration, metal production, power plants)
    - medical diagnostics (e.g. respiratory gas analysis)
    - explosive detection

[1] Q-MACS - a registered trademark of neoplas control - stands for Quantum Cascade Laser Measurement and Control System

Figure 1-1: Example of Q-MACS for process control with two lasers

Table 1-1: Selection of Q-MACS measurable species together with their limit of detection (LOD) at 37.5 mbar

Molecule	Q-MACS trace 56	Q-MACS trace 76	Q-MACS trace 200	Q-MACS process[2]
NH_3 ammonia	40.00 ppb	3.00 ppb	0.70 ppb	2.00 ppm
H_2O water	1.00 ppm	75.00 ppb	30.00 ppb	50.00 ppm
CH_4 methane	200.00 ppb	10.00 ppb	4.00 ppb	20.00 ppm
C_2H_2 acetylene	150.00 ppb	10.00 ppb	4.00 ppb	15.00 ppm
C_2H_4 ethylene	140.00 ppb	10.00 ppb	4.00 ppb	10.00 ppm
C_2H_6 ethane	2.00 ppm	100.00 ppb	40.00 ppb	200.00 ppm
O_3 ozone	300.00 ppb	30.00 ppb	12.00 ppb	25.00 ppm
H_2O_2 hydrogen peroxide	300.00 ppb	20.00 ppb	8.00 ppb	40.00 ppm
CHOH Formaldehyde	160.00 ppb	12.00 ppb	3.00 ppb	20.00 ppm
CO carbon monoxide	25.00 ppb	3.00 ppb	0.70 ppb	5.00 ppm
CO_2 carbon dioxide	6.00 ppb	0.50 ppb	0.15 ppb	500.00 ppb
OCS carbonyl sulfide	20.00 ppb	1.00 ppb	0.30 ppb	1.50 ppm
SO_2 sulfur dioxide	200.00 ppb	20.00 ppb	8.00 ppb	20.00 ppm
H_2S hydrogen sulfide	120.00 ppm	9.00 ppm	3.00 ppm	1000.00 ppm
NO nitric oxide	200.00 ppb	10.00 ppb	4.00 ppb	15.00 ppm
NO_2 nitric dioxide	50.00 ppb	4.00 ppb	1.00 ppb	10.00 ppm
N_2O nitrous oxide	20.00 ppb	2.00 ppb	0.80 ppb	2.00 ppm
SF_6 Sulfur hexafluoride	50.00 ppb	4.00 ppb	1.50 ppb	2.50 ppm
SiF_4[3] silicon tetrafluoride	100.00 ppb	8.00 ppb	2.00 ppb	6.00 ppm
NF_3[3] nitrogen trifluoride	180.00 ppb	15.00 ppb	4.00 ppb	10.00 ppm
C_4F_6[3] hexafluoro-2-butyne	180.00 ppb	15.00 ppb	4.00 ppb	10.00 ppm
CF_4[3] tetrafluoromethane	180.00 ppb	15.00 ppb	4.00 ppb	10.00 ppm

[2] Assuming double path through a chamber of 50 cm diameter
[3] These species lead to broadband spectra with respect to the spectral resolution by QCL, thereby overlapping needs to be taken into account