Recent Advances of Trace Gas Sensors based on Diode and Quantum Cascade Lasers

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Abstract

Diode and quantum cascade lasers can be used for trace gas detection in ambient air based on absorption and photoacoustic spectroscopy. Advances in spectroscopic detection techniques have resulted in minimum detectable absorbances of 10^{-5} in several applications.

Summary

This talk will focus on the development of compact, highly sensitive and selective trace gas sensors based on diode and quantum cascade lasers (Fig. 1) for the detection, monitoring and quantification of several key trace gas species. These gas sensors address important analytical instrumentation needs in atmospheric chemistry, environmental monitoring, urban and rural emission measurements, chemical analysis and industrial process control as well as medical and biomedical applications. The use of diode laser pumped nonlinear optical sources based on difference frequency generation (DFG) and quantum cascade lasers permit targeting strong fundamental rotational-vibrational transitions in the mid-infrared spectral region (3-24 μm), which are one to two orders of magnitude more intense than overtone transitions in the near infrared.

Novel pulsed and continuous wave (cw) quantum cascade distributed feedback (QC-DFB) lasers fabricated by band structure engineering and grown by molecular beam epitaxy offer an attractive new radiation source for mid-IR and far infrared laser absorption and photoacoustic spectroscopy in the 3 to 140 μm spectral range. The most technologically developed system to date is based on intersubband transitions (type-I QC laser) in InGaAs/InAlAs heterostructures [1]. More recently, type II interband cascade (IC) lasers operating in the 3.3 to 4.2 μm spectral region have been demonstrated and applied to the detection of CH_4 at ~ 3.47 μm and H_2CO at ~ 3.53 μm [2,3]

The architecture and performance of several sensitive, selective, real-time gas sensors based on mid-infrared cw and pulsed QC-DFB lasers will be described. To date we have detected 12 gases (CH_4, N_2O, CO_2, CO, NO, H_2O, NH_3, C_2H_4, COS, SO_2 C_2H_5OH, and C_2HO) as well as some isotopic species at the ppm to the ppt level [4,5]. This may require various sensitivity enhancement schemes such as a multipass gas absorption cell, cavity ring down spectroscopy, off axis integrated cavity output spectroscopy and photoacoustic absorption spectroscopy (PAS) which can realize minimum detectable

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absorbances in the range from 10^{-7} to 10^{-9} cm^{-1}. We recently introduced quartz-enhanced photoacoustic spectroscopy (QEPAS) as an alternative method to perform laser based PAS where the acoustic signal build up occurs in a high-Q piezoelectric quartz crystal instead of a low-Q gas filled resonator (Fig. 2), [6]. Several current examples of trace gas sensors used in real world applications will be reported.

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Figures

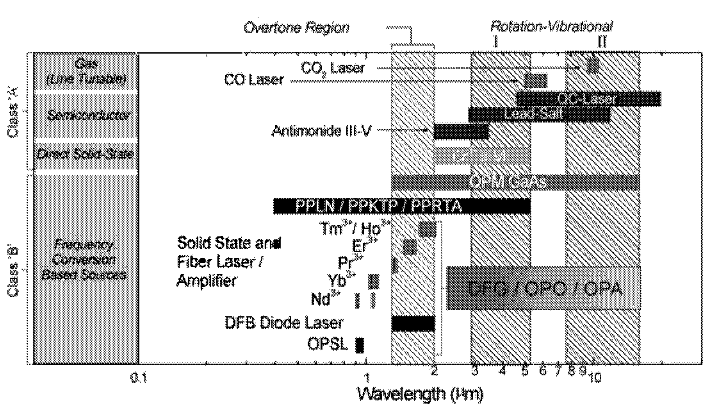

Fig. 1 Laser sources and typical wavelength coverage. OPSL, optically pumped semiconductor laser. It should be noted that recently tuning range for interband and intersubband OCLs extend from 3-140 μm.

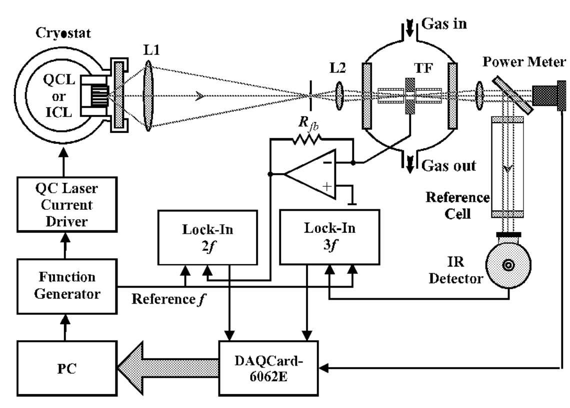

Fig. 2 QCL based Quartz-Enhanced Photoacoustic Spectrometer.