6th International Conference on "Mid-Infrared Optoelectronics Materials and Devices"
St Petersburg, Russia, 28 June–2 July 2004, Ioffe Institute

Applications of quantum cascade lasers in trace gas analysis and chemical sensing

Frank K. Tittel, Yury. Bakhirkin, Robert F. Curl, Anatoliy A. Kosterev, Stephen So, Damien Weidmann and Gerard Wysocki
Rice Quantum Institute, Rice University, Houston, TX 77251-1892, USA

One of the principal applications of quantum cascade lasers (QCLs) is in chemical sensing, since these lasers can access directly the mid-infrared spectroscopic fingerprint region ($\sim 2-25\ \mu$m), where most gaseous chemical substances possess strong fundamental rotational-vibrational transitions [1-3]. To date we have detected 11 gases (CH_4, N_2O, CO_2, CO, NO, H_2O, NH_3, C_2H_4, COS, SO_2 and C_2H_5OH including isotopic signatures of carbon and oxygen at the ppm to the ppb level using QCLs. This talk will focus on the development of compact trace gas sensor platform technology based on QCLs and their application to sensitive, selective and quantitative trace gas detection. Current application topics include: atmospheric chemistry and environmental monitoring, urban and industrial emissions measurements, chemical analysis and industrial process control and medical applications.

QCLs possess the key properties required for a mid-infrared spectroscopic source: (1) sufficient optical power to ensure high signal-to-noise ratios, (2) narrow linewidths and single frequency to obtain high selectivity, (3) mid-infrared wavelength coverage with type I and II QCLs, (4) continuous and broad wavelength tunability without mode hops, (5) quasi-room temperature operation, (6) good beam quality and (7) high reliability and compactness. Until recently quasi-room temperature operation of QCLs was only possible for pulsed operation, but recently the first thermoelectrically-cooled, continuous wave (cw), mid-infrared, single frequency QCL was reported, which will greatly facilitate the use of QCLs in spectroscopic applications [4].

Current examples of QCL applications being investigated by us include trace gas sensing in NASA applications relevant to spacecraft environmental monitoring and advanced life support using quartz enhanced photoacoustic spectroscopy [5], high precision measurements of $^{13}CO_2/^{12}CO_2$ isotopic ratios at 4.3 μm (see Fig. 1) and noninvasive medical diagnostics of various human diseases by means of breath analysis. One specific application is the measurement of NO in exhaled breath, since the presence of NO is an indicator of several physiological and biochemical processes taking place in the human body, in particular in assessing the severity of airway inflammation (i.e. asthma). A gas sensor based on a cw single frequency QCL operating at $\sim$ 5.2 μm (1900 cm^{-1}) and off axis integrated cavity output spectroscopy is being developed to measure ppb levels of NO concentration in breath (see Fig. 2 and 3).

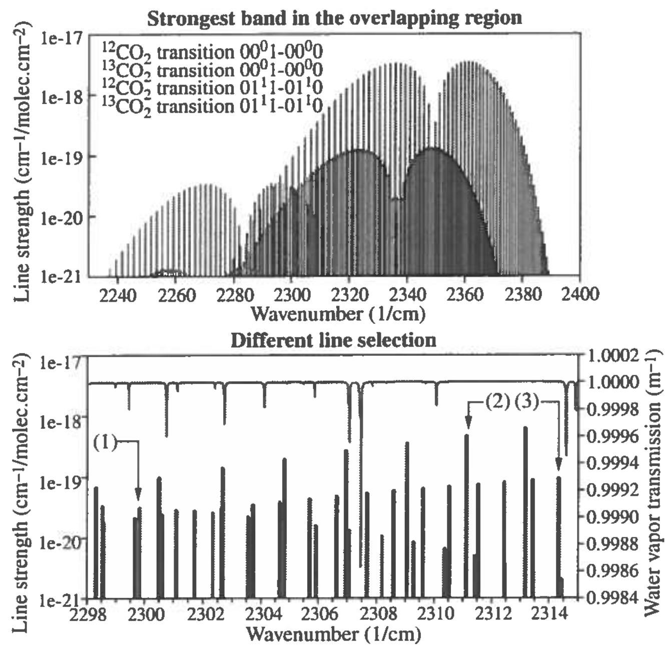

Fig. 1. CO_2 Line Selection: $^{13}CO_2$ and $^{12}CO_2$ overlapping region at 2300 cm^{-1}.

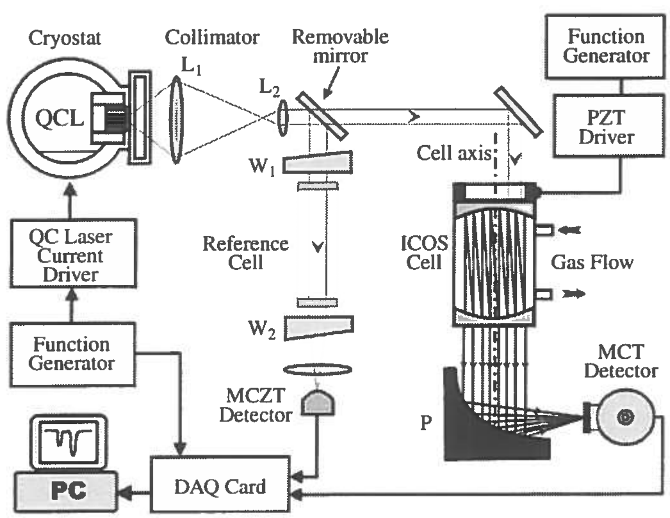

Fig. 2. Off-axis ICOS gas sensor.