

Infrared trace gas sensing technologies for environmental, biomedical, industrial and nuclear security applications.

F. K. Tittel^{1*}, R. F. Curl¹, L. Dong, J. Doty¹, R. Lewicki¹, A. Kachanov², A. A. Kosterev¹, S. So³ and D. Thomazy¹
 (1) Rice Quantum Institute, MS 366, Rice University, 6100 Main St., Houston, TX 77005, USA
 (2) Skymoon Research & Development, 3671 Enochs Street, Santa Clara, CA 95051, USA
 (3) Princeton University, B321 Engineering Quad, Princeton, NJ 08540 (USA)
 e-mail: fkt@rice.edu

Recent advances in the development of sensors based on the use of diode and quantum cascade lasers (QCLs) for the sensitive, selective detection and quantification of both small and large molecular gas species with resolved and unresolved spectroscopic features respectively will be reported. Different spectroscopic techniques have been employed such as laser absorption spectroscopy (LAS), cavity ring down spectroscopy (CRDS) or quartz enhanced photoacoustic spectroscopy (QEPAS) [1]. Applications include concentration measurements of single and multiple trace gas species for applications in such diverse fields as environmental monitoring, industrial process control and medical diagnostics [2]. In this presentation we will focus on several examples of real world sensor applications, which include fire and post fire detection in spacecraft habitats [3], CO₂ monitoring in and around sequestration reservoirs, real time monitoring of ammonia concentrations in non-invasive breath analysis and safeguarding nuclear materials (UF₆).

Considerable experimental and analytical progress has been made with QEPAS since its first demonstration in 2002. Recently we have investigated the effect of humidity and microresonator effects on detection sensitivity of different chemical species, in particular the diameter, length and material of microresonators for QEPAS. We have also investigated the feasibility of ultra sensitive QEPAS detection in a power build-up cavity (PBC) to increase the optical power available for QEPAS by locking a low power diode laser (and in the future a QCL) to an optical enhancement cavity using optical feedback. Such a technique would bring QEPAS detection sensitivity to the same level as obtained with CRDS. An intra-cavity power of ~ 290 W was achieved with a 20 mW diode laser operating at 1283.8 nm. A minimum detectable absorption loss of $3.2 \times 10^{-10} \text{ cm}^{-1}/\text{Hz}^{1/2}$ for a weak atmospheric water line was demonstrated with PBC-QEPAS with a prospect of 40-fold improvement.

Details of the design, performance evaluation in both laboratory and at a NASA testing facility in Las Cruces, NM of two novel laser based gas sensor platforms using both a compact (15 cm long) multipass gas absorption cell (4.6 m effective optical path length) and QEPAS for the detection of 4 fire signature gases: < 5ppm CO, <1 ppm HCN, <1ppmv HCl and CO₂ in the 300 ppmv -3% range with ~ 1 sec update rates will be reported. These sensors use 4 long lifetime diode lasers at 2334 nm for CO, 1529 nm for HCN, 1742 nm for HCl and 1572 nm for CO₂ monitoring, respectively.

Significant progress has been made in real time ammonia detection of exhaled human breath with both a distributed feedback and tunable external cavity quantum cascade laser based QEPAS sensor operating at ~ 10.5 μm. Ammonia is associated with liver and kidney disorders. Typical concentrations of ammonia in healthy human breath may vary from tens to few hundreds ppb, whereas elevated levels (> 1 ppmv) indicate significant pathology.

State-of-the-art semiconductor laser technology based on infrared absorption spectroscopy offers the opportunity to detect both in situ and remotely trace gases of specific interest to the International Atomic Energy Agency (IAEA) charged with the detection and verification of nuclear materials and activities on a global basis. Laser absorption spectroscopy (LAS) has been proposed as a spectroscopic technique capable of accurate uranium enrichment determination of UF₆ samples. The use of LAS technology for the development of a field deployable instrument for use at enrichment sites requires a robust, compact, sensitive and selective sensor platform. The development of a cw, room temperature DFB QCL based spectroscopic source operating at 7.74 μm (1291 cm⁻¹) and its performance evaluation with an UF₆ analyte simulant (C₂H₂) will be described.

References:

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