SEMICONDUCTOR LASER BASED TRACE GAS SENSOR TECHNOLOGY: RECENT ADVANCES AND APPLICATIONS

Laser Based Trace Gas Sensor Technology

FRANK K. TITTEL*, GERARD WYSOCKI, ANATOLIY KOSTEREV, and YURY BAKHIRKIN
Rice University, 6100 Main Street, Electrical and Computer Engineering Department – MS 366, Houston, TX, 77005, USA

Abstract. Recent advances in the development of sensors based on infrared diode and quantum cascade lasers for the detection of trace gas species is reported. Several examples of applications in environmental and industrial process monitoring as well as in medical diagnostics using quartz enhanced photoacoustic spectroscopy and laser absorption spectroscopy will be described.

Keywords: Trace gas detection, near infrared diode lasers, mid infrared quantum and interband cascade lasers, quartz enhanced photoacoustic spectroscopy, laser absorption spectroscopy.

1. Introduction

Infrared laser absorption spectroscopy is an extremely effective tool for the detection and quantification of molecular trace gases. The demonstrated sensitivity of this technique ranges from parts per million by volume (ppmv) to the parts per trillion (pptv) level depending on the specific gas species and the detection method employed [1,2]. The spectral region of fundamental vibrational molecular absorption bands from 3 to 24 μm is the most suitable for high sensitivity trace gas detection. However the usefulness of the laser spectroscopy in this region has been limited by the availability of convenient tunable laser sources. Real world applications (see Table 1) require the laser source to be compact, efficient, reliable and operating at near room-temperatures. Existing options include lead salt diode lasers, coherent sources based on difference frequency generation (DFG) described in Part IV-2, optical parametric oscillators (see Parts II-8 and IV-3), tunable solid state lasers (see Part II-5), quantum and interband cascade lasers. Sensors based upon lead salt diode lasers are typically large in size and require

* fkt@rice.edu

M. Ebrahim-Zadeh and I. T. Sorokina (eds.), Mid-Infrared Coherent Sources and Applications, 467–493.

TABLE 1. Wide Range of Gas Sensing Applications.

Urban and Industrial Emission Measurements
Industrial Plants
Combustion Sources and Processes (e.g. early fire detection)
Automobile and Aircraft Emissions
Rural Emission Measurements
Agriculture and Animal Facilities
Environmental Gas Monitoring
Atmospheric Chemistry (e.g. ecosystems and airborne)
Volcanic Emissions
Chemical Analysis and Industrial Process Control
Chemical, Pharmaceutical, Food & Semiconductor Industry
Toxic Industrial Chemical Detection
Spacecraft and Planetary Surface Monitoring
Crew Health Maintenance & Advanced Human Life Support Technology
Biomedical and Clinical Diagnostics (e.g. breath analysis)
Forensic Science and Security
Fundamental Science and Photochemistry

cryogenic cooling because these lasers operate at temperatures of <90 K. DFG sources (especially bulk and waveguide PPLN based) have been shown recently to be robust and compact [3–5].

The recent advances of quantum cascade (QC) and interband cascade (IC) lasers fabricated by band structure engineering offer an attractive new source option for mid-infrared laser absorption spectroscopy with ultra-high resolution and sensitivity [6]. The most technologically developed mid-infrared QC laser source to date is based on type-I intersubband transitions in InGaAs/InAlAs heterostructures [7–13, Part II-1]. More recently interband cascade lasers (ICLs) based on type-II interband transition have been reported in the 3–5 μm region [14–17]. Other QCLs based on GaAs/AlGaAs material system have been reported as well [18, 19].

The vast majority of chemical substances have vibrational fundamental bands in the 3 to 24 μm region, and the absorption of light by rotational-vibrational transitions of these bands provides a nearly universal means for their sensitive and selective detection. Furthermore, near infrared spectroscopy from 1.3 to 3 μm can be used effectively in the quantification of numerous trace gas species. This application can use ultra-reliable, room temperature, single frequency distributed