Detection of Trace Gas Contaminants Using Diode Laser Based Methods

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Summary

In recent years, tunable diode laser based sensors have found widespread applications to the sensitive and selective detection of environmentally important atmospheric trace gases in real time. The motivation for such precise species concentration measurements of gaseous compounds in ambient air includes such diverse fields as urban (e.g., automobile traffic, air quality in large enclosed structures), industrial (e.g., fence line perimeter monitoring in the petro-chemical industry, combustion sites and waste incinerators), rural (e.g., horticultural greenhouses, rice agroecosystems) emission studies, chemical analysis and control for numerous manufacturing processes (e.g. HF, NH_3 and HCl in semiconductor fabs and HF in aluminium smelters), biomedical sensing of physiologically important molecules (e.g., NO and CO), atmospheric chemistry (e.g., CO, CO_2, CH_4 and H_2CO in global studies of the environment), and spacecraft habit monitoring.

Numerous analytical tools based on different optical and non-optical techniques have been developed in the past. However, an ideal gas sensor technology that meets such diverse requirements as high sensitivity and selectivity, wavelength tunability of multi-component detection, fully computerized, room temperature operation (i.e. no liquid nitrogen cooling), large dynamic range, compactness, high reliability (insensitive to vibrations and large variations in ambient temperature), relative ease of use and cost-effectiveness in terms of initial and maintenance costs, is a challenging research and development task. Recent significant technological advances of semiconductor diode lasers and tunable all solid state lasers, novel bulk and waveguide infrared nonlinear materials for parametric optical frequency conversion, optical fiber amplifiers and couplers, thermoelectric cooled low noise infrared detectors, and advanced data acquisition and signal processing techniques have had a considerable impact on development of state of the art diode laser based trace gas sensors.

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Such new diode laser based spectroscopic sensors are beginning to provide excellent sensitivity and selectivity of an increasing number of organic and inorganic gaseous compounds in the infrared spectral region. This region consists of both the near infrared (0.8 μm to 3 μm) that can be accessed by an increasing number of distributed feedback (DFB) telecommunications diode lasers and the mid-IR region (3 μm to 20 μm) by lead-salt and antimony based diode lasers, quantum cascade lasers, and compact sources based on difference-frequency mixing of commercially available diode and fiber lasers. Performance characteristics of several recent optical architectures of mid-IR gas sensors that have been developed and applied to real world spectroscopic applications in the laboratory and field will be discussed. An effective method to increase sensitivity is to increase the effective optical path. This is possible for in-situ, open path atmospheric measurements, but numerous applications require a compact extractive technique based on multipass cells (White, Herriott designs).

The near infrared region is characterized by the presence of the first and second overtone and combination bands for many important gases. However, the transition strengths of the fundamental vibrational bands in the mid-IR are at least one to two orders of magnitude stronger, making this spectral regime the region of choice for high-sensitivity laser absorption spectroscopy. The detection sensitivity of current diode laser based gas sensors using direct absorption spectroscopy is limited by etalons and laser feedback noise to 10^{-5} to 10^{-6} relative absorption. In addition to direct absorption spectroscopy various techniques such as frequency modulation, two-tone frequency modulation spectroscopy, balanced homodyne or ratiometric detection and cavity ring down spectroscopy (CRDS) can be utilized. Of these, only CRDS offers a means for avoiding the baseline variations caused by etalons which often limit sensitivity.

In summary, the progress of tunable diode laser absorption spectroscopy (TDLAS) based gas sensors and their acceptance in numerous applications has made dramatic strides in recent years.

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