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FLAIR - Field Laser Applications in Industry and Research

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Abstract: Diode-lasers find increasingly applications in industry, medicine and environmental monitoring, but still measurements challenges have to be solved in the fields of stable isotopes, trace gas emissions from ecosystems and on in-situ airborne stratospheric platforms.

OCIS Codes: (140.2020) Diode-Laser; (300.6260) Spectroscopy; (010.1120) Air Pollution Monitoring

1. Introduction

Optical analytical techniques meanwhile are well established not only in research laboratories but also continue to find an increasing number of applications in industrial gas analysis and environmental sciences. Spectroscopic methods allow a highly specific detection of a broad range of substances as the absorption spectrum of a gas under investigation has a characteristic fingerprint structure for each molecule.

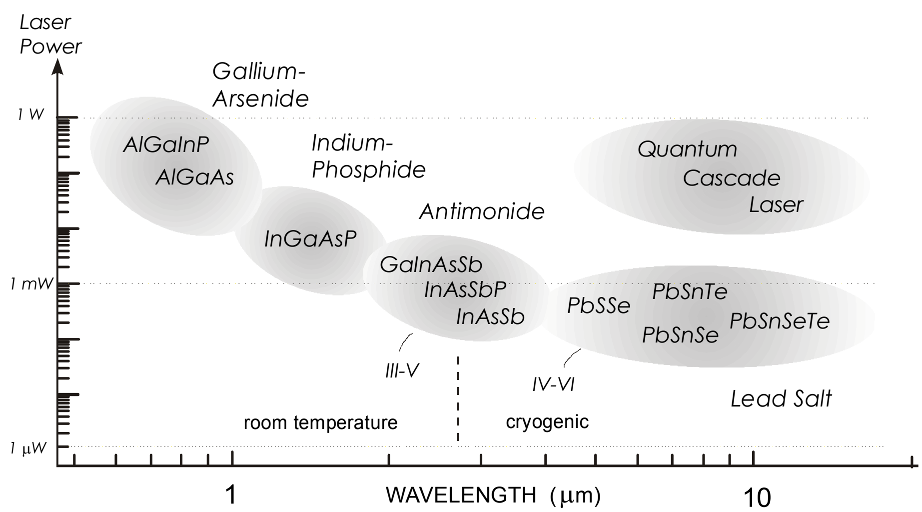

Fig. 1: For combination and overtone bands in the near-infrared various diode-lasers are available, while the mid-infrared fundamental bands are covered by cryogenic lead-salt diode-lasers and quantum cascade lasers.

Indium-phosphide, antimonide, lead-salt and quantum cascade (QC) lasers cover the spectral range from the near- to the mid-infrared (Fig.1) and, therefore, can be used as versatile tunable laser sources for fast and highly sensitive trace gas analysis [1]. This measurement technique is based on the absorption by the fundamental strong absorption bands of most gases in the mid-infrared spectral region and by overtone and combination bands in the near infrared, where the oscillator strength is typically one to several orders of magnitude weaker than the IR-fundamental band. The most important application of diode-lasers is their use with a long-path cell to provide high sensitivity local measurements, when a single narrow laser line scans over an isolated absorption line of the species under investigation. Modulation techniques have made it possible to detect absorptions below 10^{-6} for integration times of about 1 sec [2]. This sensitivity, when combined with an optical path length through an absorbing sample of several tens of meters, translates into parts-per-billion (ppb) to parts-per-trillion (ppt) detections for many molecular species in the infrared and for many gases with near-IR absorption bands, this sensitivity corresponds to detection of sub-parts-per-million (ppm) concentrations over a path length of a few meters. When the wavelength of the diode-laser is tuned over an absorption line, a periodic, often non stationary, fringe structure is superimposed to the desired signal from the absorption of the target gas, frequently called the 'étalon-effect' and the problem of fringe reduction is still a key issue to improve sensitivity for high-end applications [3].

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In this paper a brief overview of the present status of commercial diode-lasers and systems for industrial applications will be given and some measurement challenges in atmospheric reseach will be addressed.

2. Industrial TDL systems and applications

During the Industrial Session held at the 4th International Conference on Tunable Diode Laser Spectroscopy TDLS-2005 in Florence, Italy [4] it has been pointed out by J. Kunsch that Tunable Diode Laser Spectroscopy (TDLS) has managed to turn from a "promising technology" into an "established technology" in the industry within the last years [5]. In 2004 the first company announced the sale of their 1.000th TDLAS instrument in history [6] based on the use of NIR wavelengths. Key gases are O_2, NH_3, CH_4 and water vapour. Recent results are closely linked with improvements in lifetime and a reliable supply of specially tailored lasers. Meanwhile laser manufacturers (that even compete in certain areas) are teaming up to commercialize laser technology and do cooperate on developing and marketing VCSELs [7], DFB-lasers [8] and QC-lasers [9]. Despite all progress of room temperature cw-operation of QC-lasers the focus of industrial applications is still on pulsed operation. The reasons are rather simple: First, good experimental results have been achieved by pulsed technology [10] Second, pulsed QC-lasers are easier to supply and third: Lifetime indications of pulsed QC are promising. The commercial availibility of new lasers like room temperature cw optical parametric oscillators for mid-infrared spectroscopy [11], distributed feedback diode-lasers and tunable femtosecond fiber lasers [12] and external cavity systems [13] are a precondition for broadly established TDLS applications. Also new source modules, electronics and signal processing components [14,15] help industrial manufacturers to go from "high end to low cost volume applications" [16]. Besides laser based systems for medical diagnostics and breath analysis [17] and novel trace gas analyzer for environmental measurements [18-20] meanwhile for industrial process monitoring the next generation of economically priced gas analyzers is commercially available. These models are compact, rugged and efficient [21]. Gas analyzers using TDLS in the near infrared have been widely accepted in the industry for applications where other techniques have failed to operate satisfactorily. Typical applications so far have been for emission control of pollutants such as HF, HCl and NH_3 where an in-situ TDL measurement is superior to other spectroscopic techniques both with respect to sensitivity, accuracy and reliability [22]. Establishing diode laser technology as a new standard for gas analytics in process industries means to meet all the up-to-date requirements on process instrumentation in terms of easy handling, robustness, high stability, maximum availability, and low cost-of-ownership. Beside that, the analytical performance needed for technical relevant applications is sometimes a challenge even for a diode-laser spectrometer [23].

3. Measurement challenges in atmospheric research

Besides these industrial applications there are also selected high end applications for specialized and dedicated instruments. Many of these applications can be found in environmental research. A key issue in ecosystem research and atmospheric studies being conducted today is the ability to quantify small concentrations of trace gases. For biosphere/atmosphere or air/sea exchange trace gas flux measurements based on the eddy correlation technique in addition high temporal resolution up to 10Hz is required [24]. Another challenge is the in-situ measurement of stable isotope ratios of stable molecular species (isotopomers) [25]. The measurement of isotopic ratios is a useful tool for studies in geochemistry, volcanology, biomedicine and atmospheric sciences. In environmental research, isotopic analysis provides information of the sources, sinks and transport of substances, and allows to estimate budgets of the major greenhouse gases. The measurement of the isotopic composition of water vapor is an important issue. Transport processes from the earth surface to the stratosphere are associated with a strong dehydration and due to isotopic fractionation, growing depletion in the stable isotopic ratios of water vapor can be observed with increasing height. Studies of the isentropic transport of water vapor into the lower stratosphere and the vertical transport into the tropopause region (extratropics) or the tropical transition layer (TTL) will contribute to an improved understanding of the water vapor budget in the upper troposphere and the lower stratosphere (UT/LS) and will help to assess the potential change of water vapor and its impact to the earth´s radiation budget and climate change. For airborne measurements new spectroscopic instruments will be designed for the recently approved German High-Altitude - LOng range research aircraft HALO [26], which will be able to fly up to 15500 meters and 8000 kilometers before refueling and, therefore, allows to study the tropical transition layer and almost the entire lowermost stratosphere (LMS). Other airborne research platforms which are currently being used for atmospheric research including tunable diode-laser systems are NASA´s DC-8 [27], WB-57, ER-2 [28], HIAPER and the M55 Geophysica (Fig. 2). The scientific payload of the Geophysica is made by 17 different instruments, built by many European research groups, ranging from IR interferometers, UV–VIS DOAS spectrometers, lidars, particle counters, gas chromatographs and the TDL systems ALTO and COLD [29].

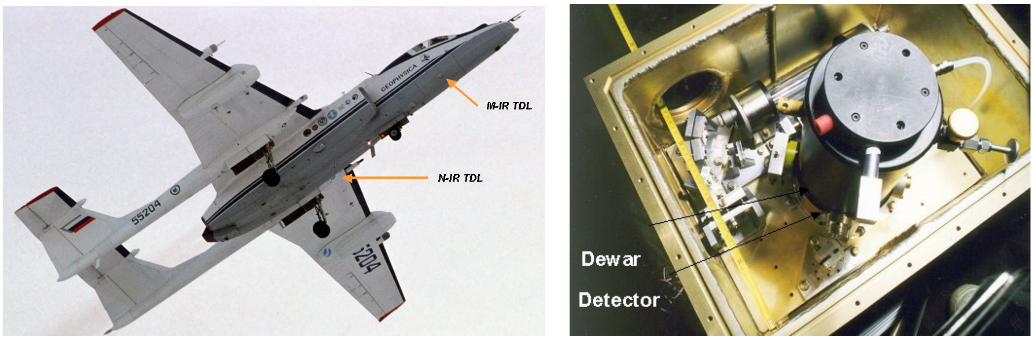

Fig. 2: Location of the NIR system ALTO and the MID-IR lead-salt TDL COLD on M55 Geophysica [29].

One of the major issues in stratospheric mixing processes is the temporal evolution of fine scale structure in the atmosphere, such as the filamentary structures that break-off from the polar vortex, or localized intrusion of tropospheric air into the stratosphere. The high time resolution of diode-laser based measurements of N_2O and CH_4 is of importance to classify an air mass as typical for the interior of the polar vortex or of the mid-latitude stratosphere. Airborne applications are still a measurement challenge for the state-of-the-art spectroscopic instrumentation [30].

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