OPTON LASER INTERNATIONAL

FROM PLATFORM TO VOLUME

Dr. Lars Hildebrandt, nanoplus, considers the importance of TDLAS gas detection systems for hydrocarbons in the mid-infrared spectral region.

The use of laser spectroscopy in research and industry has grown for decades. It is a workhorse in process control, gas concentration monitoring, environmental tracing, and medical applications, where tunable diode laser absorption spectroscopy (TDLAS) is applied – it is even used in space. A platform for all wavelengths between 760 nm and 16 µm[1] for high-end applications, with only a few hundred installations per year, is widely available. Special markets with high volume demand use this technology for integration into volume products.

TDLAS exploits the rotational-vibrational optical absorption features of gases for single-mode semiconductor laser-based trace gas detection. In practical terms, this allows sensors to detect trace gas concentrations with exceptional selectivity and sensitivity, often down to parts-per-trillion levels. The inherent wavelength stability of DFB lasers also enables long-term operation without recalibration – an essential requirement for industrial monitoring systems, safety-critical applications, and reliable medical devices.

Long-lifetime TDLAS instruments stand out by combining low cost of ownership with robust, fail-safe, and easy-to-use operation. As illustrated in Figure 1, a standard TDLAS setup consists of a wavelength tunable distributed feedback (DFB) semiconductor laser emitting monochromatic light at the absorption line of the trace gas, an optical lens to collimate the light, a gas cell containing the gas to be measured (CH_4 in this case), and a photodetector (PD) to capture the transmitted beam.

Major improvements in sensing speed, noise reduction, and sensor miniaturisation are achieved by targeting the strongest absorption bands of the measured gases. For many industrially and environmentally significant gases, these bands fall within the mid-infrared (MIR) wavelength region at approximately 3 - 6 µm. Figure 2 shows that many important gases (like CO_2, CO, HCl, NO, N_2O, H_2O, H_2S, SO_2, NO_2, NH_3, or O_3) as well as most hydrocarbons (like CH_4, CH_2O, HCN, C_2H_2, C_2H_6) exhibit their strongest or at least most pronounced absorption features in the MIR.

A complex coupled DFB laser design is used by nanoplus, based on an overgrowth-free etching process. The complex coupling is achieved by combining a ridge waveguide structure with metal gratings positioned on both sides of the ridge, on top of the waveguide layer, as shown in Figure 3. This image also illustrates a typical power current (PI) curve of such a device at different temperatures. Continuous wave (CW) output power of a few MW together with tuning ranges of a few nm are sufficient for most TDLAS applications.

There are three types of semiconductor DFB lasers commercially available. In bipolar laser diodes, electrons and holes have an optical interband recombination at the p-n-junction. This transition has a high energy gap, which allows shorter wavelengths (760 nm - 3 µm) to be reached with these devices. In interband cascade lasers (ICL), electrons and holes have an optical interband recombination at a W-shaped quantum well of the semiconductor material.[2] The energy of this transition is lower than those of bipolar diodes, which is why ICLs cover higher wavelengths (3 - 6 µm, and recently even above 6 µm).[3] Finally, in quantum cascade lasers (QCL), the valence band is irrelevant for the optical transition. Electrons and holes have an optical intraband recombination within the conductive band of the semiconductor material. The energy is even lower compared to ICLs, so the achievable CW wavelengths are higher (4 - 11 µm). The usable wavelength bands of ICLs and QCLs overlap: in general, QCLs are used for applications requiring higher optical power, and ICLs are installed when low power consumption and use at room temperature is essential.

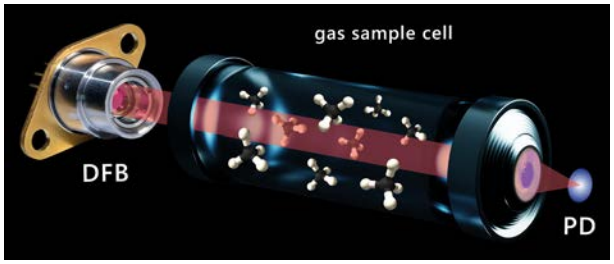

Figure 1. A standard TDLAS setup. The collimation lens is integrated into the housing containing the DFB chip. The second lens is integrated into the absorption cell.

Applications

For TDLAS, single-mode semiconductor DFB laser sources emitting CW in the 760 nm - 11 µm wavelength range have been commercially available for several years from a small number of vendors. Especially in the MIR, the low power consumption of ICLs makes them preferable to QCLs, so most applications nowadays feature ICLs. Applications of ICLs in hydrocarbon (and other) gas detection systems include the following:

Leakage control in gas pipelines

Undetected methane leaks can create hazardous situations, from gas production sites to end-use applications. Hence, maintenance of underground pipelines produces high costs. Moreover, methane leaks are an important source of greenhouse gases (GHG).

CO_2 is a natural diluent in oil and gas deposits. When it reacts with H_2S and H_2O, steel pipelines corrode. Real-time monitoring of CO_2 and H_2O at natural gas custody transfer points is necessary to avoid contaminated gas from flowing downstream. Immediate measures may be taken to purify the natural gas.

With TDLAS, a strong tool is available to manufacture portable, reliable, and small leak detectors.

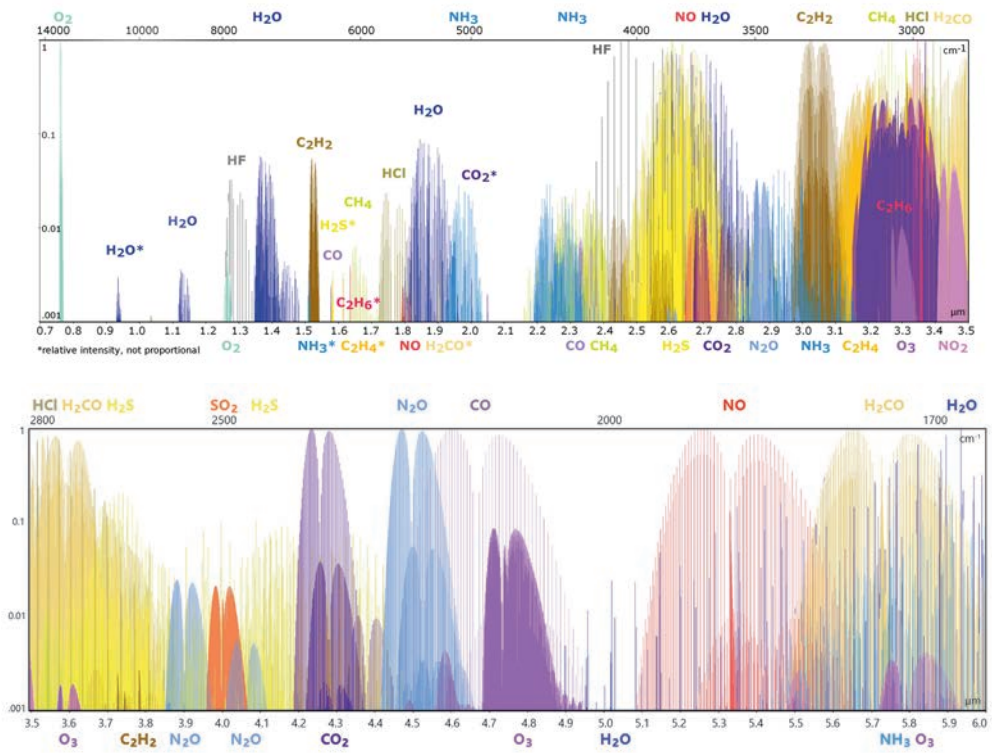

Figure 2. Absorption lines for gases between 760 nm and 6 µm (from Hitran database). E.g., the line strength of methane at 3270 nm is two orders of magnitude larger than the widely used feature at 1654 nm.

Fire warning in coal mines

Early fire warning detection technologies rely on highly sensitive and selective detection of carbon monoxide and methane. TDLAS enables a very fast, 100% fail-safe, and reliable detection scheme. Coal-fired power plants, steel mills, or biomass deposits use these detectors to increase process and workers' safety.

Emission control of GHGs

GHGs and climate change have driven global efforts to monitor emissions of pollutants such as methane and ethane. The global warming potential of methane is about 30 times higher than that of CO_2. Studies commissioned by the

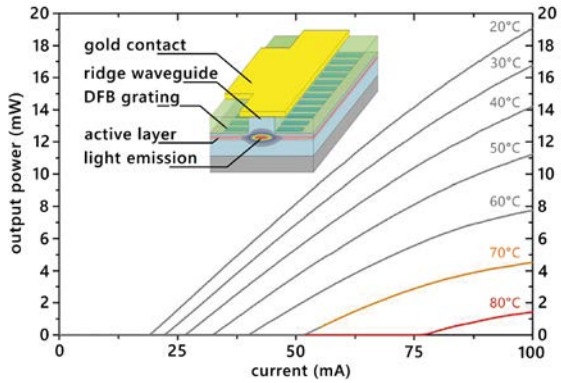

Figure 3. A complex coupled DFB ICL laser design with a typical PI-curve at different temperatures.

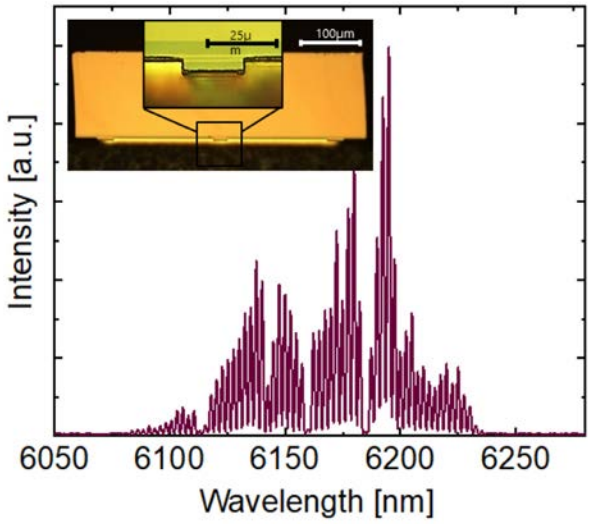

Figure 4. An ICL above 6 µm in CW mode, mounted epi-side-down.

US Environmental Protection Agency (EPA) quantify methane emissions caused by increased natural gas exploration and production in the US. Ethane equally has a critical impact on climate change with emissions related to fossil fuel and biofuel consumption, biomass combustion, and natural gas losses. Hence, trace gas detection is an important tool to monitor GHGs.

Combustion control in high temperature processes by quantifying CO_2 and CH_4

Continuous monitoring of CO_2 or CH_4 concentrations is essential for the efficiency of high-temperature processes in incinerators, furnaces, or petrochemical refineries. Controlling CO_2 levels in combustion processes simultaneously reduces GHG emissions and improves processes.

Emission control by methane source identification

Ethane is a byproduct of methane emissions. The ethane ratio varies between methane emissions from thermogenic and biogenic sources, which allows for differentiating oil and gas reserves from those of livestock, landfills, wetlands, or stagnant water.

Combustion control in integrated gasification fuel cell cycles

The methane content of syngas is controlled to improve the combustion efficiency of integrated gasification fuel cell cycles.

Quality control of ethylene production in the petrochemical industry

Acetylene is a byproduct in the cracking process of ethylene production. The petrochemical industry minimises the compound via hydrogenation. This process enhances the purity and overall quality of the produced ethylene.

Explosion prevention by monitoring acetylene

Acetylene is widely used in gas welding due to its easily adjustable flame. However, it becomes highly explosive when mixed with oxygen or subjected to sudden changes in pressure or temperature. For workers' safety, continuous monitoring of acetylene concentrations is essential.

Monitoring of workplace exposure to formaldehyde

Formaldehyde has been used in consumer and industrial products since the beginning of the 19th century. Currently, formaldehyde production accounts for more than 20 million tpy, of which 50% is processed as adhesives in pressed wood panels. In 2004, formaldehyde was classified carcinogenic by the International Agency for Research on Cancer. Since then, formaldehyde concentrations have been strictly controlled in the production process and in finished products. Laser-based measurement systems are required to detect formaldehyde at levels down to parts per billion. A similar instrument detects formaldehyde in the air aboard the International Space Station (ISS).

Outlook

nanoplus' recent cooperation with TU Vienna made ICLs beyond 6 µm possible.[3] Before, wavelengths between 6 - 7 µm in CW mode were not reported. Figure 4 shows an ICL at 6.2 µm from that cooperation which will soon be commercially available. The next step in this development process will be to integrate a grating as in Figure 3 to fabricate tunable DFB-ICLs between 6 - 7 µm.

Conclusion

The technology, applications, and cooperation outlined in this article show the importance of TDLAS gas detection systems, especially for hydrocarbons in the MIR spectral region. Many new instruments for novel and common applications have entered the market in the last five years with improved specifications like lower detection limits and improved usability. These cost-effective solutions are a benefit for users by leading to a greater return on investment.

References

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Semiconductor Light Sources for Hydrocarbon Gas Analysis

Near-IR to Mid-IR / Process Control / Safety / Emission Monitoring

Light Sources for Hydrocarbon Detection

Distributed Feedback (DFB, ICL, QCL) Laser: 760 nm - 14000 nm

Fabry-Pérot (FP) Laser : 760 nm - 14000 nm

Mid-Infrared LED (MIR-LED): 1750 nm - 6500 nm

Superluminescent Diodes (SLD): 760 nm - 2900 nm

Applications

Process gas analysis and optimization

Leak detection and safety monitoring

Emission measurement and regulatory compliance

OEM gas sensor platforms

Advantages

Custom wavelengths from Near-IR to Mid-IR tuned to your specific hydrocarbon absorption lines

Long-term stability & reliability

Tailored design from prototype to series production

Designed and manufactured in Germany

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Congratulations to NASA's Artemis II on their successful Moon mission with our lasers!

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