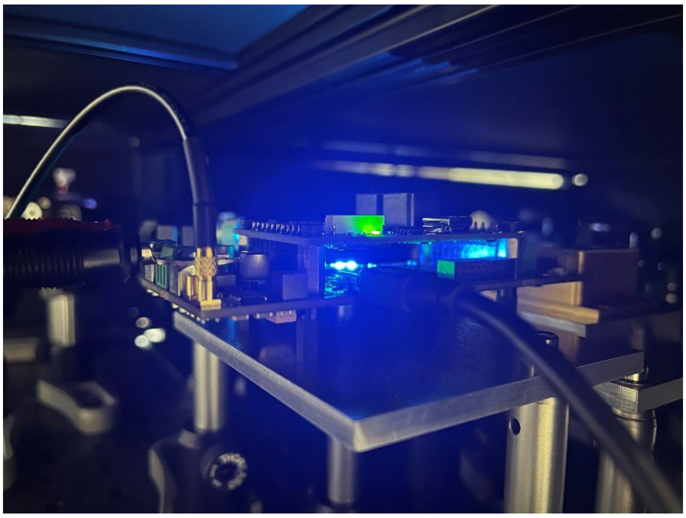
mirSense case study
November 2023
PTB – Dr. Zhechao QU
Intrapulse spectroscopy



Above is a picture of the setup at PTB and we see the rear of the driving PCB from mirSense where a cable sends a TTL signal to generate the QCL pulse.

Based in Northern Germany in the lovely wooded outskirts of the city of Braunschweig, PTB (Physikalisch-Technische Bundesanstalt) is Germany's highest authority when it comes to metrology and ISO standards and one of the tasks of PTB is helping out the German decarbonized society come of age. More specifically, the task at hand is finding out ways to emit less CO2 emissions when using combustion engines inside factories, boats, airplanes or cars.

Because nuclear power plants are no longer allowed in Germany, one major goal is to use the hydrogen (H2) and ammonia (NH3) molecules as promising energy carriers because these molecules can store energy created by wind or solar generators. The two molecules seem to have differences in their potential use and while hydrogen seems the preferred molecule for pure fule cells, it is also more difficult to produce and liquify than ammonia because in liquid phase it requires high pressure and low temperature. Yet it seems both molecules can be used together as NH3 could also be used to produce H2 since one molecule of NH3 contains one atom of Nitrogen. Different departments of PTB work on different topics such as how to produce hydrogen and ammonia, how to use them as fuel cells, how to address safety issues linked to explosive levels of H2 or how to measure H2. A real-life problem is for example, when hydrogen is injected and diluted in the gas that circulates in the national gas grid, how can you precisely measure and invoice in the monthly gas bill 4.5L and not 5L of hydrogen used by the household for the kitchen stove?

The department in which Dr. Zhechao QU works is tasked with measuring the species (molecules) generated by the combustion engines to better understand the processes at stake. The first fundamental goal is to have the lowest uncertainty possible during measurement and be as close as possible to ISO standards and the second goal is to replicate in the laboratory reactor the harsh industrial temperature and pressure conditions to simulate and measure the species. Because the combustion happens in a very short period of time (less than a millisecond) the method of laser diagnostics is preferred over the one of mass spectrometer, the latter being too slow. PTB has a FTIR instrument that is used to measure many species in samples of exhaust fumes but this instrument is not useful for real-time measurements because it's response time is not fast enough and it's also invasive meaning you need to insert a probe into the gas chamber and this can become an issue in harsh environments. When it comes to choosing the laser source, QCLs are ideal because they emit in the fingerprint region of the species to be detected (NO, NH3, N2O, NO2..). For H2 measurement though, ICLs are the right candidate as they emit around 2µm wavelength where H2 has an absorption line, albeit a weak one (to compensate for the weakness of the absorption line, PTB works on a kilometer-long multipass cell setup).

The setup of PTB is a shock tube, meaning a metal tube that on one end has a mechanical piston that will increase the pressure of a Helium and Argon mixture up to 100 bars and this pressure will then rupture a diaphragm and create a shock wave that will roll forward in the tube and enter a gas cell that contains the prepared gas mixture. This gas mixture has been prepared by another instrument and it can be a mixture of Argon, O2 and H2 for example. Sometimes, this gas cell and the pipe are heated for an hour to avoid condensation. Argon is sometimes preferred to nitrogen in the mixture because Argon has no nitrogen atom and therefore will not create measuring interferences if the species to be measured are NO or N20 or N20. When the shock wave reaches the prepared mixture, this mixture will auto-ignite and reach a temperature more than 10 000 Kelvins. PTB uses a high-speed camera to study the flame and sends a laser beam through a window in the shock tube to quantify the species by reading through another window the power level on a detector (absorption spectroscopy).

One thing that Dr. Zhechao QU liked about the mirSense system is the high power of the QCL generated at the required wavelength for NO measurement (~5.2µm wavelength) and also the fact that the driving electronics of mirSense can pulse the laser at 1 MHz, much faster than a traditional function generator that is typically limited to tens of kHz. The software provided by mirSense is easy to use and lets the user easily change the pulse length as well as the QCL chip temperature. PTB has built a home-made water-cooling box to evacuate the heat from the base plate of the HHL and the base plate of the QCL is typically maintained around +20°C. The lab environment of PTB is air-conditioned all year round and kept at the same room temperature.

PTB colleagues have done extensive experiments with the intrapules absorption spectroscopy and preparing a manuscript on this work.