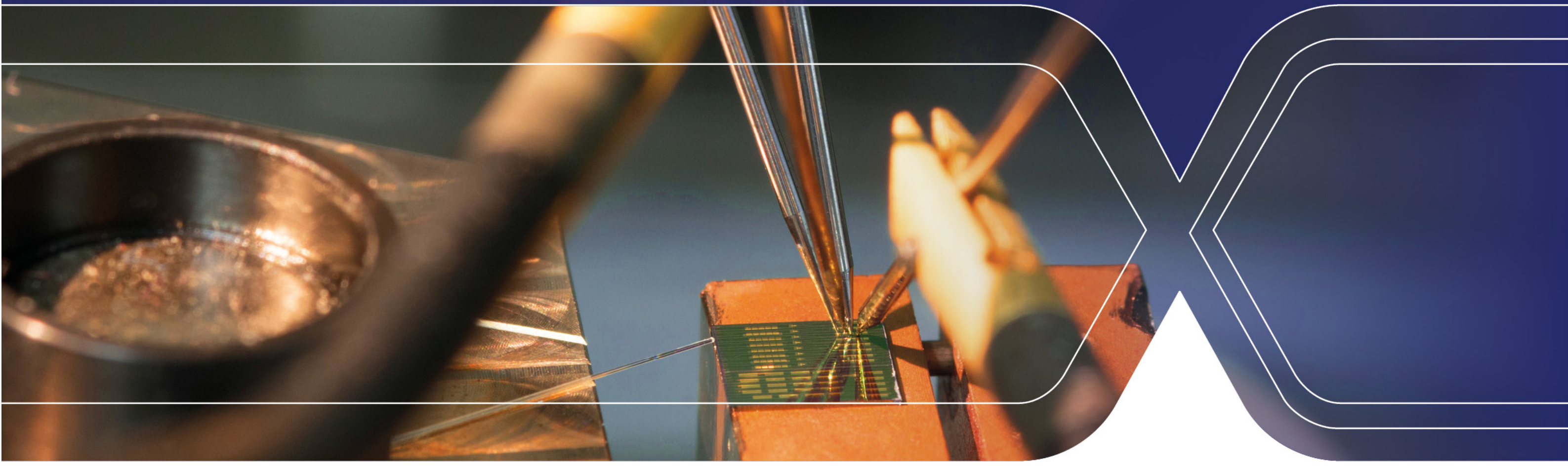
# Application Note

## Photonic Integration for Gas Sensing

JePPIX
Platform for Photonic Integration



### Photonic Integrated Circuits for Gas Sensing

Gas sensors and analyzers find applications in many fields, including (bio)chemical industry for safety and environmental monitoring, automotive for exhaust monitoring, agriculture for greenhouse gas and odor regulation, and general environmental sensing in urban areas for monitoring pollutants and warning people with respiratory diseases. Human health and safety and greenhouse emissions are the main rationales.

Gas sensors are typically based on a variety of technologies, including electrochemical, semi-conductor and photonics based approaches. The technology of choice depends on gas species and the required sensitivity, but a general trend is that the more sensitive sensors are more expensive than the less sensitive ones. These cost levels can differ by as much as a factor of ten higher cost for a factor of ten increase in sensitivity, as shown below. At the same time, sensitive sensors tend to have larger footprints, with the parts-per-billion (ppb) sensitivity levels being rack-mountable, while parts-per-million (ppm) level sensors can be handheld or smaller. Other aspects to consider are specificity, i.e., how well can a single gas be detected in an environment with other gases, and the possibility for detecting multi-species detection.

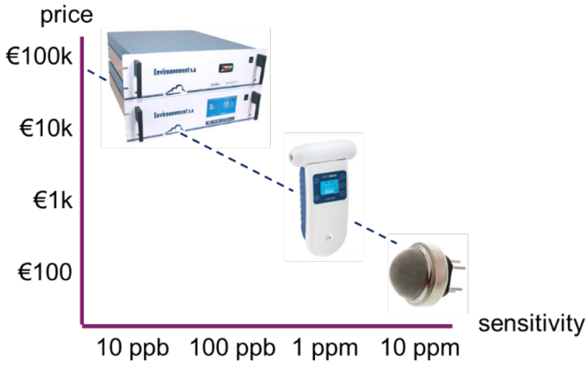



*Figure 1: Schematic overview of price vs. sensitivity performance for ammonia sensors.*

#### InP Photonic Integrated Circuits (PICs)

*Optical chips or PICs can contain tens to hundreds of optical components. While electronic integrated circuits (EICs) consist of transistors, capacitors, and resistors, a PIC consists of, for example, lasers, modulators, photodetectors, and filters, all integrated on a single substrate. Several application fields, such as data- and telecom, sensing, and lidar are already using or are considering the use of PICs for their products. This PIC technology is accessible to users without a cleanroom, through so-called multi-project wafer runs and open access foundries. InP based technology is commercially available through SMART Photonics and Fraunhofer Heinrich-Hertz-Institut. Access is individually coordinated by JePPIX.*

Government regulation and monitoring of environment and greenhouse gases, industrial safety standards, and urban area health hazard prevention are clear opportunities for the development and implementation of low-cost and ubiquitous gas sensors. New technologies, like the internet of things (IoT) are considered key enablers for such large-scale implementation of sensors and sensor networks. This application note discusses the potential use of photonic integration technology for such low-cost, small-footprint and potentially sensitive gas sensors.

## The opportunity for photonic integration

A frequently used technique for photonics-based gas sensing is tunable laser diode absorption spectroscopy (TDLAS), as shown below. With mature laser diode and detector technology, originally developed for fiber communications, sub-ppb sensitivities can be achieved[1]. Such telecom lasers work in the 1500 nm to 1600 nm wavelength regime, where gases, such as $NH_3$, $N_2O$, $CO_2$, CO, $H_2S$, $C_2H_2$ and $CH_4$ have absorption lines.

Photonic integration (see inset) can combine all elements of a TDLAS gas sensor on a single photonic integrated circuit (PIC). Indium phosphide based PICs can have integrated tunable lasers, operating in the 1500 – 1600 nm regime[2]. Photodetectors, as well as connecting waveguides, can also be integrated on the PIC. These PICs are typically fiber-coupled, and can interface with recently developed hollow-core fibers[3] and fiber-coupled gas cells[4] for a complete sensor. This would make a robust gas sensor.

In the field of fiber sensors, the use of PICs has already been commercialized for increased sensitivity and lower weight and footprint[5]. The optical transceiver market shows that PICs can be integrated with driver and signal processing electronics in form factors with volumes below 20 $cm^3$ and at cost levels of a few €100. This shows the opportunity and potential for PIC based gas sensors in terms of volume manufacturing, footprint and low cost. The ease of integration with electronics also offers the possibility for wireless communications and, hence, their use in the IoT.

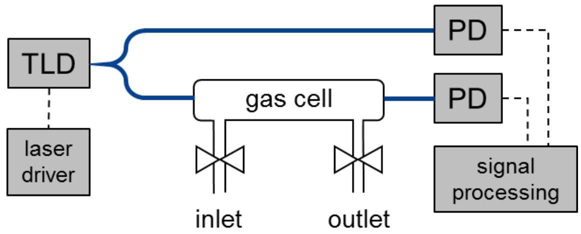



*Figure 2: Schematic of the TDLAS technique. A tunable laser diode (TLD) is coupled to a gas cell (or hollow-core fiber, or free-space propagation). The transmitted light is detected by a photodiode (PD). A reference PD, collecting the laser light directly, is used to create a balanced PD.*

## Technical challenges

The PIC and overall system need to be carefully designed for the target application. In the near-infrared telecom wavelength regime, overtone absorption lines are to be used, which have lower absorption than the lines found in the mid-infrared regime. Low-noise tunable lasers are required, which can be realized by using, e.g., extended cavity lasers on the PIC.

The lack of absorption strength can be partially offset by the superior detectors available in PIC technology, with near-unity quantum efficiency and very low noise. Moreover, techniques well known in telecommunication, such as homodyne and heterodyne detection, can be considered and easily implemented on a PIC, for additional sensitivity.

Packaging of the PIC with electronics and with fiber coupling, at low cost and large volume, is an important aspect. Commercial solutions, e.g., as offered through the PIXapp Pilot Line, are available. In any case, the fiber-coupled PIC solution, especially using hollow-core fiber, avoids issues with mechanical stability and pointing stability.

## Discuss your application with us

If you are interested in knowing more about the capabilities and use of InP PIC technology for gas sensing, contact JePPIX or the JePPIX Pilot Line[6].

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[1] http://lasersci.blogs.rice.edu/files/2014/05/overtone_AP1.pdf
[2] https://doi.org/10.1109/JPHOT.2015.2493722
[3] http://www.nktphotonics.com/lasers-fibers/product/hollow-core-photonic-crystal-fibers/
[4] http://www.wavelengthreferences.com/products/single-mode-flowcells/
[5] http://www.technobis.com/products/extreme-fiber-sensing/
[6] http://www.jeppix.eu/pilotline