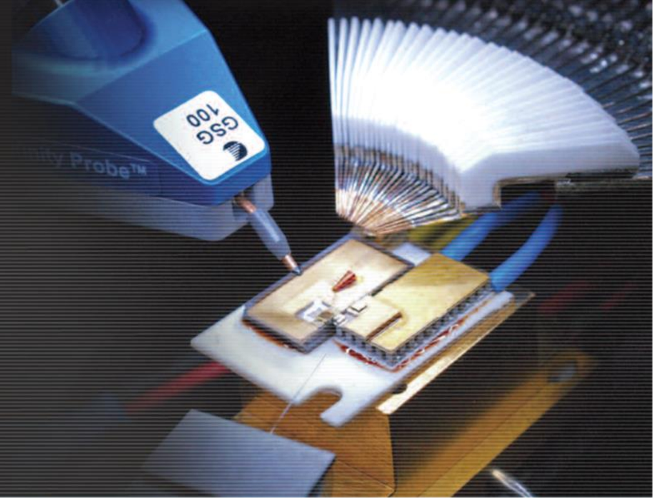
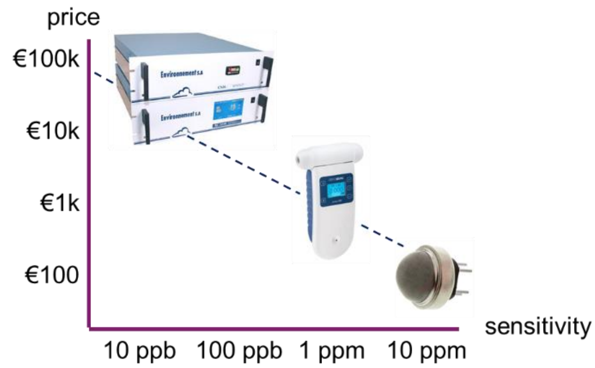


Photonic Integrated Circuits for Gas Sensing

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, semiconductor 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.

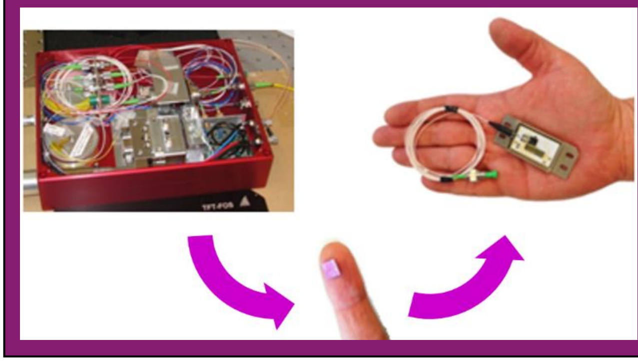


Schematic overview of price vs. sensitivity performance for ammonia sensors.

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.

Photonic Integrated Circuits (PICs)

Also known as optical chips, PICs can contain tens to hundreds of optical components. While electronic ICs consist of transistors, capacitors and resistors, a PIC consists of, for example, lasers, modulators, photodetectors and filters, all integrated on a single substrate. These PICs are nowadays extensively used commercially, mainly in datacom and telecom.
PIC technology has now become accessible to users without a cleanroom, through so-called multi-project wafer runs and open foundries. Indium phosphide based technology is commercially available through SMART Photonics and Heinrich Hertz Institute. Access is coordinated by the JePPIX platform: http://www.jeppix.eu/.



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

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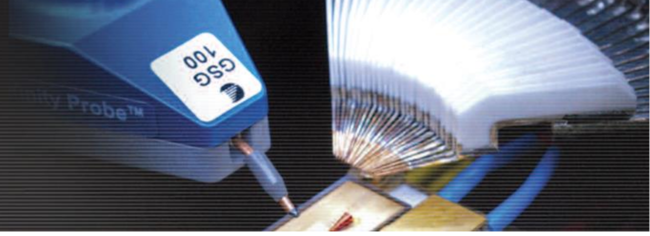
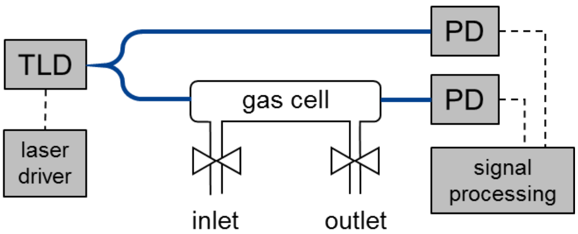


achieved[1]. Such telecom lasers work in the 1500 nm to 1600 nm wavelength regime, where gases, such as NH_3, N_2O, CO_2, CO, H_2S, C_2H_2 and CH_4 have absorption lines. Photonic integration (see inset) can combine all elements of a TDLAS gas sensor on a single photonic integrated circuit (PIC). Indium 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.



Schematic of the TDLAS technique. A tunable laser diode (TLD) is coupled to a gas cell (or hollow-core fiber, or free-space propagation), where specific wavelengths are absorbed. 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 still a challenge. However, commercial solutions, e.g., as offered by Technobis IPPS and Linkra are becoming 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 to know more about the use of PIC technology for gas sensors, please contact Martijn Heck, coordinator of the PICs4All Application Support Center (ASC) at Aarhus University, Denmark. We are currently running a project for gas sensors, Ecometa, funded by Innovation Fund Denmark, with a focus on sensitivity analysis and prototype fabrication. We are set up to help you do a feasibility study for the use of PICs for gas sensing applications.

The PICs4All consortium[6] is funded under the Horizon 2020 framework and brings together expertise to support end-users, like academia, research institutes and industry, with PIC technology. The ASCs can help you connect to the eco-system of designers, foundries, packaging and test services.

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