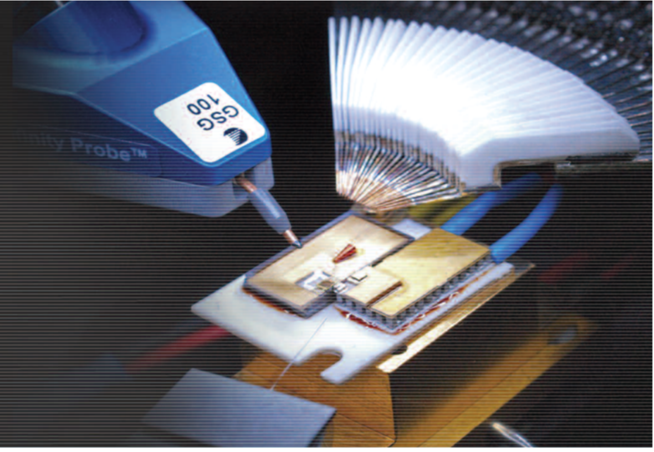


Photonic Integrated Circuits for on-chip biological sensing

Photonic on-chip sensors are **based on waveguide structures and rely on precision interferometry** such as Mach-Zehnder Interferometers (MZI)[1], ring-resonators (RR)[2] and bi-modal waveguides (BiWG)[3]. A review of the different on-chip sensor structures can be found in reference 2, alongside with their performance in terms of commonly used parameters such as the bulk and surface limit of detection (LOD). On chip sensors are based on the fact that the optical field in a waveguide is partially guided outside the waveguide core, the so-called **evanescent field**. This sensing technology has been **successfully applied for the clinical diagnostics**, with extremely sensitivity and selectivity and directly in few microliters of human fluids. Examples[4] include infectious bacteria (at few cfu/mL) and their corresponding multidrug resistance, early detection of colorectal cancer, fast detection of Tuberculosis in patients´ urine or the analysis of microRNA biomarkers at aM level related to bladder cancer progression, helping the clinicians to implement rapidly a personalize treatment for each patient.

Technologies

As depicted in Fig. 1**, micro-fabrication techniques**, such as selective area trenching, can be employed to expose part of the waveguiding layer to the outer medium. The figure aims at illustrating the concept of evanescent field sensing, and portrays a vertical slice of a photonic chip, with one guided optical mode having a part of the energy (evanescent wave) in the outer part of the waveguide core. When in contact with the outer media, the propagation of this field along the waveguide is influenced by the change of the refractive index due to the presence of substances such as gases or liquids or the adsorption of solid thin films or biomolecules in the vicinity of the waveguide surface.

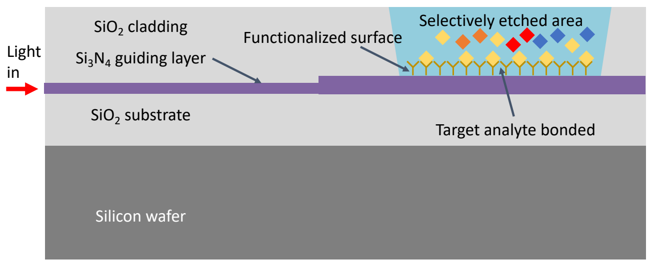
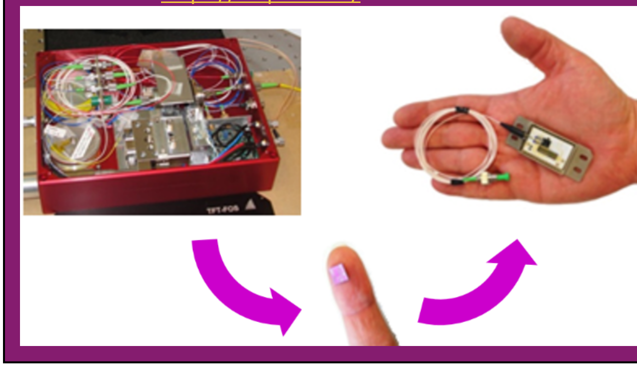


Fig. 1 – Example of a waveguide photonic integration sensor on Silicon Nitride (sideview).

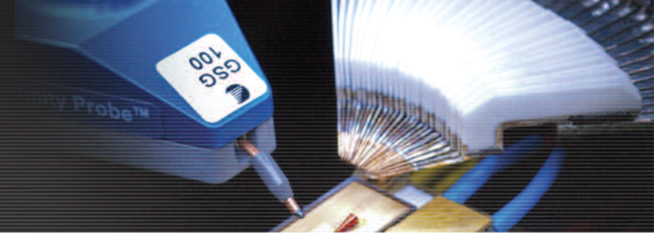
Photonic Integrated Circuits (PICs)

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, waveguides, photodetectors and filters, all integrated on a single substrate. These PICs are nowadays extensively used commercially, mainly in datacom and telecom, becoming popular also in sensing.

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. Silicon nitride technology is commercially available at LioniX Intl. Access is coordinated by the JePPIX platform: http://www.jeppix.eu/. Silicon nitride technology is also accessible through the ePIXfab Silicon photonics alliance platform http://www.epixfab.eu/ - H2020 actions related are: i) specific to bio-photonics PIX4life https://pix4life.eu/ ii) generic packaging https://pixapp.eu/ and iii) proof-of-concept support via ACTPHAST https://actphast.eu/



Despite the relative simplicity of these integrated optics devices, as compared to other photonic chips aimed at other application domains such as tele/datacom, they do require complementary science and engineering to result into a working photonic chip-based-sensor. One key aspect is **surface functionalization**. The target analyte may be present with many other substances in the same liquid or gas sample. Functionalization consists on the chemical activation of the waveguide surface to allow the anchoring of selective receptors in order to provide the required affinity for the target analyte. Therefore, functionalization is a key ingredient of photonic chip sensors, since it aims at guaranteeing that only the target analyte is recognized at the sensor surface. In an interferometric sensor, a phase change is induced in the propagated light, due to the refractive index



change due to the accumulated mass at the waveguide functionalized surface. This phase change can be transduced to an intensity change through the aforementioned **interferometric devices**, which are shown in Fig. 2. The figure shows a waveguide based interferometric sensors that consist of different parts, within a straight waveguiding structure. The light is injected in a first waveguide section were only single mode propagation is allowed. This section interfaces a second one, where the waveguide is thicker, allowing then two vertical modes[2] to propagate. On top of this thick waveguide, a third section is formed where the waveguide cladding is selectively removed (Fig. 2 'sensor area'). This is the chip area subject to functionalization, and where the target analyte will be recognized later on. Since the waveguide section at this part does also support two modes, but with different penetration of evanescent field, the influence of the attached analyte on each mode is different. Hence, the light at the end of the sensor chip is collected by an intensity detector with two different areas. The relative currents generated at this two-section detector, depends on the interference of the two modes in the bi-modal waveguide. Since the interference changes with the amount of analyte, the sensor is able to track concentration changes in a solution where this analyte is present.

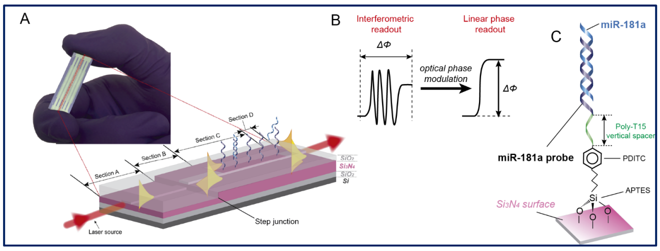


Fig. 2 Bi-modal waveguide interferometric bio-sensor.

Traditionally, bio-photonic on-chip sensors have been developed with silicon nitride as guiding material and in the visible and near-infrared wavelength ranges. Operating in the visible range brings the advantages of avoiding the light absorption by water in other wavelengths range (as IR) and the transparency of the biomolecules in this region. Several silicon nitride integration platforms exist which provide access to generic integration technologies for sensing[5].

Discuss your application with us

If you want to learn more on the use of PIC technologies for the implementation of photonic chips for sensing, please contact the PICs4All consortium. Our consortium can support you in the techno-economic evaluation of photonic integration geared towards your products and applications. Support may be given as well in the design and characterization. In the framework of the EU H2020 PICs4All project the partners offer free-of-charge guidance to companies, research institutes and academia interested in development and implementation of their commercial products, using photonic devices. The PICs4All consortium is funded under the EU Horizon 2020 programme and brings together expertise of nine European Application Support Centers (ASCs). The ASCs can guide you through the existing eco-system of design houses, foundries, packaging and test services.

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