PIX4life: photonic integrated circuits for bio-photonics

(Invited paper)

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ABSTRACT

As key enabling technology, photonics has become critical in many fields. Advances in fabrication technologies have realized photonic integrated circuits not only for telecommunication wavelengths but also in the mid-infrared, and very importantly, in the visible. The latter can strongly benefit bio- and life-science applications where visible light is very commonly used in bulky and expensive optical systems. Through PICs Robust optical functionalities can be realized cost-effectively. However, the technology was not openly available until very recently.

The pilot line, PIX4life, was established with the aid of the European Union to facilitate European R&D employing visible light PICs for visible applications, targeting mainly health and bio-science applications.

Keywords: Pilot line, PIX4life, silicon nitride photonics, biophotonics, life sciences, visible wavelength, short near-infrared

1 INTRODUCTION

Nowadays, there is a growing interest in life sciences towards Silicon Nitride (SiN) based Photonic Integrated Circuits (PICs). This has been precipitated thanks to the transparency of SiN which expands from through the visible range of the electromagnetic spectrum up to 2600 nm that is achieved by modern deposition techniques [1]. PICs transparent in the visible and sort near-infrared ranges can be employed in many bio- and life-science applications where traditional bulk optical systems are currently been employed.

The use of SiN-based monolithic PICs in such applications provides very important benefits due to their mechanical, chemical, thermal and electro-optical stability, reduced size and light weight [2]. By integrating these photonic components in a single chip, a miniature system can be developed that often also works faster and more reliable than its larger counterparts. Potentially allowing hundreds of basic building blocks, opening the door to novel complex applications [3, 4].

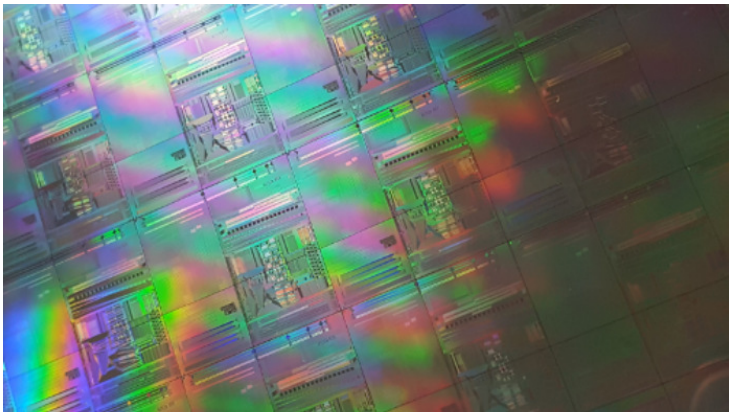

Figure 1. Example of a SiN wafer based on BioPIX technology.

Such photonic integrated circuits (PICs), produced on silicon wafers, in a standardized and automated production flow, also makes this integration technology inexpensive and scalable.

Due to their fast response, small sensing area and accuracy, SiN-based PIC sensors have been employed in research for chemical, biological and medical measurements. Some of these applications are already benefiting from PICs in biophotonics, like:

- Medical instrumentation: confocal and multi-photon imaging, DNA sequencers, optical coherence tomography, respiratory gas monitors, Raman spectroscopy, glucose monitors, flow cytometry, etc.
- Photonic Lab-on-a-chip: rapid and automated analysis of small volume samples, in-vitro and in-vivo monitoring, implantable biofluoroimaging, digital electrowetting, drug discovery, etc.
- Optical sensors to measure chemical properties such as pH changes and trace gas, indirect biosensors via fluorescence, phosphorescence or colorimetric measurements, and direct biosensors of metabolites, enzymes, environmental toxins, etc.

The implantation/adaptation of this technology by the industry has been previously delayed due to the low maturity of the fabrication process, design tools, foundry processes and packaging. In addition, the high cost of prototyping and pilot production resulted in a very slow adoption of photonic integrated circuit (PIC) technology, primarily by applications where applications can benefit from a cost reduction and middle-large scale production.

2 SILICON NITRIDE FOR THE VISIBLE

In PIX4life, we aim to tackle these issues, by maturing a high performance, high yielding and CMOS-fab compatible SiN PIC pilot line. PIX4life offers as well the complete supply chain of services for applications in the visible range (400-700 nm) and sort near-infrared (700-900 nm). Moreover, to lower the cost of prototyping the SiN technology is offered via Multi Project Wafer runs (MPWs), where multiple design from multiple users are place in the same wafer mask, sharing area and therefore costs. While MPWs provide a few copies of each design, PIX4life offers as well dedicated wafers for larger designs, or for larger number of copies of a design.

PIX4life offers services from two different foundries, each offering their own silicon nitride platform BioPIX by the foundry IMEC and TripleX^{TM}by the foundry LioniX Int., and located in Belgium and The Netherlands respectively [5, 6]. An example of a BioPIX MPW wafer is shown in Fig. 1 and an example of a TripleX^{TM}chip for visible light is shown in Fig. 2.

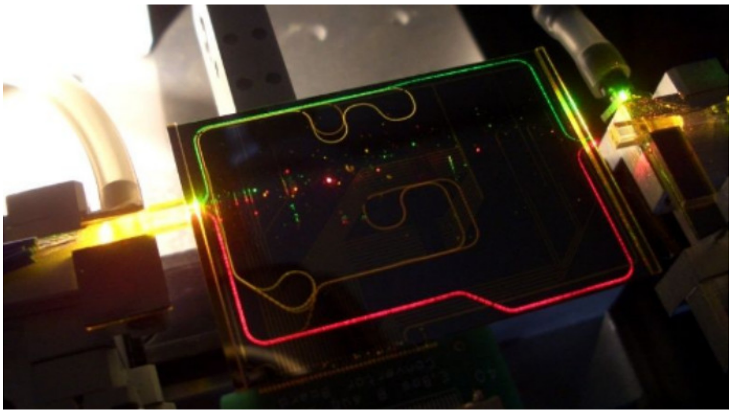

Figure 2. Example of a SiN PIC based on TripleX^{TM}.

In order to generate a SiN PIC design, that will be use to fabricate a photolithographic mask, the photonic desing software companies Phoenix and Luceda, the process design kit (PDK) for PIX4life containing all the building blocks required for most applications. Some of these building blocks have already been reported in biophotonics scientific literature. Among the reported SiN PICs we find ring resonator (RR) filters, microdisk resonators, grating couplers, wavelength combiners, multi-mode interferometers, array waveguide gratings (AWGs), and difraction gratings.

3 DEMONSTRATORS

Within PIX4life, four companies are building demonstrators based on one of the two SiN platforms. These are the following:

- *Toptica: a multispectral light source on chip*. Life science applications in the field of e.g. microscopy or flow cytometry require multiple excitation wavelengths to excite the dyes of interest. To move away from the bulky optics, Toptica is developing a fully integrated multispectral light source. This not only reduces the physical dimensions but also the cost, and it improves robustness.

- *Medlumics: an OCT-on-chip for ophthalmologists*. Medlumics aims to use the SiN photonic pilot line to produce an OCT-on-chip system operating in the near infrared, thus paving the way towards compact and cost-effective medical devices to be used in the daily practice, for example by ophthalmologists. The company's current OCT systems are based on SOI technology and use light at larger wavelengths. This is perfect for its use, among others, in cardiology, gastroenterology or dermatology. But to examine the eye, light in the near infrared is preferable. This is possible using SiN technology.
- *Miltenyi: flow cytometer with innovative laser*. Miltenyi is a German company that makes flow cytometers with a chip-based sorting module. At the moment it uses standard lasers to illuminate the fluorescent labels attached to the cells that flow past in the microfluidic channel and to identify them. The company now wants to start using biophotonics so that this laser light can be better targeted and controlled and hence enhance the sensitivity and robustness of their flow cytometer.
- *Bosch: cheaper sensors for monitoring health parameters*. Bosch wants to start using photonic sensors for monitoring health parameters such as body temperature, the composition of sweat, heartbeat, respiration rate, etc. Interaction between light and the body at the nanoscale, either by absorption or diffraction, will provide valuable information about these parameters. For engineering such a system and in order to create a reliable product, the SiN platform offers the best compromise between chemical resistance and optical performance, enabling the detection of the desired physical and chemical properties, while maintaining the small size and low power.

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