Optofluidic devices based on Silicon photonics

Eva Ryckeboer$^{1,2}$, Daan Martens$^{1,2}$, Herbert D'heer$^{1,2}$, Peter Bienstman$^{1,2}$, Dries Van Thourhout$^{1,2}$, Roel Baets,$^{1,2}$

$^1$Photonics Research Group, Ghent University - imec, Belgium
$^2$ Center for Nano- and Biophotonics, Ghent University, Belgium
email: eva.ryckeboer@ugent.be

Summary

Silicon photonics is an attractive technology platform to develop miniaturized optical systems. These optical devices often need to be exposed to liquids or gasses during operation both on a short- and long term scale. Here we illustrate the co-integration of Si photonics devices with optofluidic packaging to achieve this goal.

Introduction

Silicon photonics is an established technology for the integration of optical devices on a small semiconductor chip (<1 cm$^2$). These chips are made using CMOS processes to allow for cost-effective mass fabrication. Si photonics devices serve many applications as practically any optical functionality can be integrated. Particularly successful demonstrations can be found in the Tele- and Datacom sector and in optical sensing for life science applications. We can distinguish two large classes in optical biosensors. One class is based on detecting a change in the refractive index of the environment (i.e. a phase change) and the other class is based on detecting a change in absorption (i.e. an intensity change). The former is known as refractive-index sensing and the latter is known as optical spectroscopy. A common aspect to optical biosensors is the exposure to liquids or gasses. This requires optofluidic packaging that can be used either on a short or long term. Short term applications include e.g. diagnostic tests where a single measurement on blood is done to avoid contamination. Long term applications include implantable sensors that monitor e.g. the glucose concentration in the body or sensors that are used for inline process monitoring of pharmaceuticals. Here we will show two key approaches for combining Si photonics devices with optofluidic packaging.

Fig.1: (a) and (b) biosensors with PDMS microfluidics (c) optical switch with digital microfluidics (d)

Optical biosensors based on Si photonics fit very well into a lab-on-a-chip context. Because of the small size of the sensors (< 1 mm$^2$), only a very small amount of analytes is needed. Moreover, because of the high index contrast of this waveguide platform, small changes in the environment close to the surface of the sensor (< 100 nm) are readily detected. A prime example of a lab-on-chip sensor exploiting these assets of Si photonics was developed in the European FP7 Pocket project. Here a
point-of-care sensor for detecting a biomarker for tuberculosis in urine was realized [1]. The sensor is an integrated Mach-Zehnder interferometer (MZI) that detects the presence of the biomarker LAM. The detection principle is evanescent refractive index sensing. When LAM molecules bind to the surface of the chip, a wavelength shift in the interference pattern of the MZI is generated. To bring the sensor in contact with urine, a microfluidic chip in PDMS (polydimethylsiloxane) was developed. By using mechanical clamping the microfluidics is attached to the Si photonics sensor as shown in fig. 1a. This is a reversible attachment. To achieve a permanent attachment of the microfluidics, thermal bonding after treating both the Si chip and PDMS with an oxygen plasma can be used. An example of this permanent attachment can be seen in fig. 1b. This second optofluidic chip was used for measuring glucose concentration based on evanescent absorption spectroscopy. Here a long waveguide, routed into a spiral to minimize footprint, is immersed with a glucose solution and the light attenuation due to the glucose content is measured. Physiologically relevant glucose concentrations could be accurately measured this way [2]. Further integration of this optofluidic chip with light sources and detectors can lead to an implantable device that can continuously monitor blood glucose. Such an implant is highly relevant for diabetes patients who need to track their glucose level closely in order to stay healthy.

Another interesting optofluidic packaging approach was developed for an optical switching device [3]. Here, digital microfluidics based on electrowetting-on-dielectrics (EWOD) is used to move droplets from one position to the other to enable optical switching[4]. A droplet can be moved when a voltage is applied across electrodes in the EWOD cell. The advantage is that there is no power consumption except for when the switching action is taking place. The optical switch is an adiabatic 2x2 coupler that has two switching states depending on the liquid that is present on top of one of the waveguide arms of the coupler. This is shown in fig. 1c. When the liquid has a high refractive index, light will couple from input waveguide A to output waveguide B, leading to a cross-state of the switch. On the other hand, when the liquid has a low refractive index, the light in input waveguide A will remain in this waveguide, the bar state of the switch. The EWOD cell is placed on top of the Si photonics chip and is afterwards sealed with an UV-curable adhesive (see fig. 1d). To make sure that the droplets do not stick to the Si chip, a monolayer of FDTDs (Perfluorodecyltriethoxysilane) is applied on the top surface. This way the droplets can be easily shifted in position without dragging. Next to the electrowetting properties of the used liquids (viscosity, polarity etc), the optical absorption of the liquids are important for this combination of digital microfluidics with Si photonics technology. For the optical switch, the liquids should clearly be optically transparent. Still, droplets of a strongly absorbing liquid could also find its use. For example to minimize light at will (intensity modulation).

Conclusions
Si photonics technology combined with optofluidic packaging is a promising route for miniaturized biosensors and novel liquid-based switching devices.

References
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