Commercial SOI sensor technology

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We present a platform for the deployment of SOI based sensors in commercial applications. The platform is designed from a systems perspective and includes all aspects of a SOI sensor system, including sensor head itself, the communications infrastructure and a customized interrogation system

Integrated Photonics Industry

Integrated photonics was first introduced onto the market by the telecommunications industry from the late 1960s onwards. For the last two decades the photonics industry has grown into maturity and photonic technologies are now used in our every day life. Also, the range of applications has grown in time. Besides telecommunications, integrated photonics technologies are now as well used in the fields of lighting, imaging, photovoltaic's, optical interconnects and sensing. Up to now, each field is still a niche with its own technology and its specialized players. For example, every application uses its own material. This results in a fragmented photonics market and obstructs the arise of large industrial businesses.
We believe that integrated photonic sensors are close to commercial breakthrough and aim to bridge the gap between fundamental sciences and product. Here we discuss our vision on the shortest path for simple, low cost and disposable sensors produced in a commercial competitive manner.

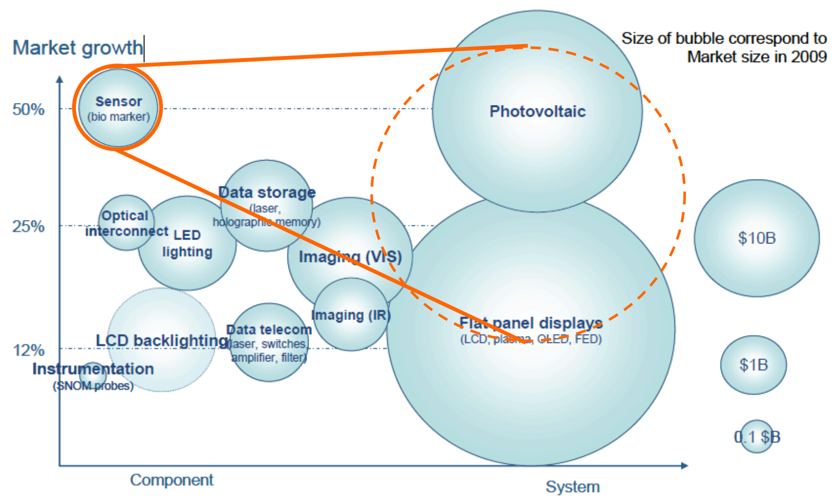

Figure 1: market growth and size for applications targeted by nanophotonics.[1] Included is our vision of the shift from photonic sensor component to photonic sensor system and an increase of market size for the coming years.

Roadmap

Using optics for sensors allows immunity to electromagnetic interference and usage of sensors in much harsher environments than electrical sensors. They also provide good sensitivity, linearity and stability. Hence, the market growth and potential of photonic sensors is high (see figure 1)[1]. At the moment the photonic sensors are still in the component segment, but by developing a full sensor system with communication infrastructure and interrogator besides the sensor head we expect to bring photonic sensing technology into the systems segment and enable a subsequent growth of the market share.
By building on the momentum of silicon electronics, silicon-on-insulator (SOI) material for photonic sensors has emerged as the most stable platform using CMOS fabrication processes for mass production. Therefore our focus lies on the sensors systems that can be implemented with CMOS-compatible SOI technologies, see figure 2.

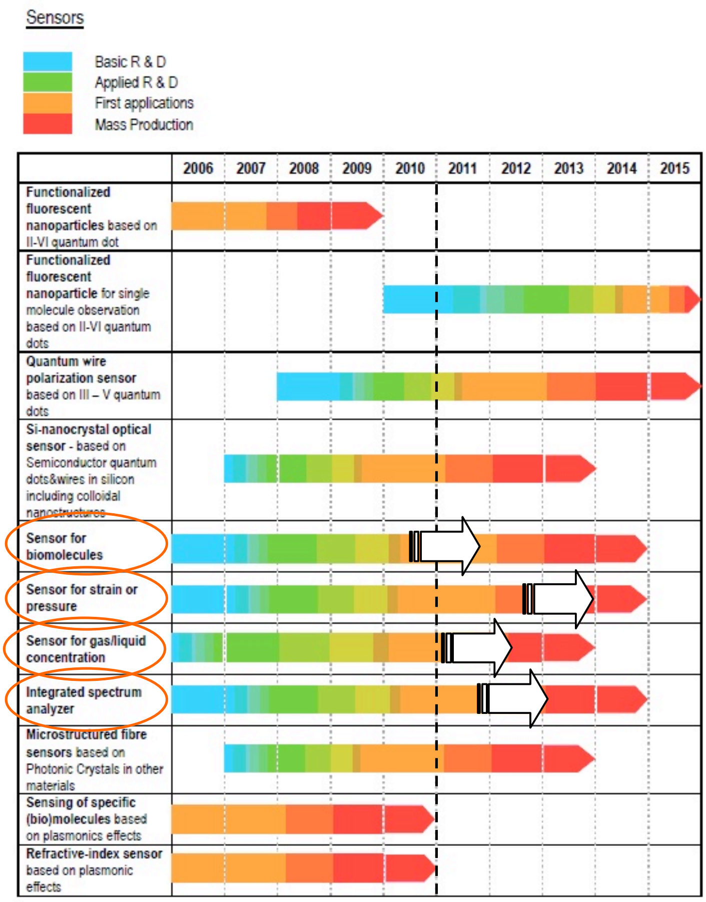

Figure 2: Timeline for photonic sensors with the most promising devices, intended as those which will experience the quickest development, and the materials and technologies with the highest impact on photonics.[1] Highlighted are the SOI sensor types on which TNO is working for commercialization and their current development status at TNO.

CMOS Technology

Photonic SOI sensors have their guiding layer in the silicon top layer which is separated by an insulating silicon dioxide layer from the silicon substrate. The band gap of silicon is such that the material is transparent to wavelengths commonly used for optical transport, around 1.3 – 1.6 µm, which allows the reuse of standardized (telecom)

equipment. Similar to an optical fiber, the waveguides are used to confine and direct light as it passes through the silicon. The advantage of a silicon device layer is the high refractive index contrast between the silicon (3.45) and the surrounding air (1.00) or silicon dioxide 1.45. Cost-wise silicon photonics is also interesting. In particular for its CMOS-compatible fabrication processes, but also for the absolute cost of silicon and SOI wafers compared to the more exotic materials as used in III-V technologies.
An important improvement of the fabrication of photonic devices is the optimization of optical lithography in recent years. Photonic sensor devices itself are not extremely small, typical feature sizes are 50 – 500 nm, but the accuracy constraints are high. Fabrication tolerances lay around 1 - 10nm, which are nowadays possible to fabricate with the 193nm node optical lithography machines.[2]

An example of a SOI based photonic sensor is shown in figure 3. Due to the extremely narrow resonance peaks of SOI ring resonators, they are suitable for the measurement of extremely small changes of the surrounding refractive index where the evanescent field travels through. Changes in this refractive index can be caused, for example, by temperature changes or the binding of molecules to the cavity's surface when a thin film of receptor molecules is deposed upon.[3]

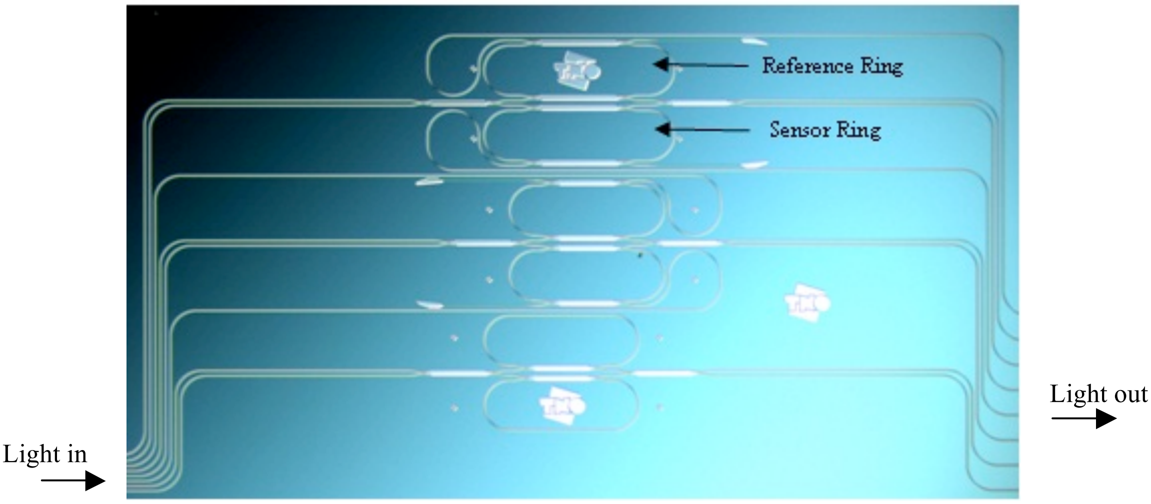

Figure 3: three pairs of reference and sensor rings that can be used for multi parameter sensing. Each pair can detect a physical parameter like temperature or pressure or a composite parameter like a chemical or biological compound.

The fabless model and ePIXfab

Most companies and institutes that like to develop photonic devices cannot afford their own silicon fab. Therefore, under EU-FP7, the ePIXfab foundry service was provided to such players. ePIXfab streamlines the fabrication technology by using a limited set of CMOS processes for photonic integrated circuits allowing academia and SME's to play in the same field as big players such as Intel and IBM. This fabless model allows high volumes as well as lot sharing, which reduce costs drastically.

In this scenario, TNO's role is to design, fabricate, characterize and qualify photonic sensor *system* prototypes in-house. After the prototype phase at TNO the customer is able to start its mass production with a commercial foundry. For the rapid prototype fabrication at TNO the "Van Leeuwenhoek Laboratory" clean room facility is used, which is equipped with an electron beam lithography track for fast mask-less device fabrication. Besides the standard characterization and qualification of the devices we also have facilities to test the devices after exposure in extreme conditions like e.g. high humidity, pyroshocks, low temperatures and radiation exposures. This broadens the application range of the photonic sensors in the medical, automotive and space industries. After development of the photonic sensor chip, TNO uses the ePIXfab services for mass production test runs and recommends the ePIXfab partners, IMEC and CEA-LETI, to our clients and partners for mass production.

Integrated Sensor Systems

In order to commercialize photonics sensors it is important to offer the whole sensor system to the market. This includes besides the sensor head also the infrastructure for communication and the interrogation. At the moment, the combination of these three elements is not yet available, which makes it unready for the market. TNO's approach in this is the development of cheap disposable sensor heads which can be placed remotely from the readout equipment using an optical fiber.[5] Also, we have taken the opportunity to develop a low cost interrogator to make the whole system more attractive for the market.

Since the whole development chain for an integrated sensor system is not yet well-defined, TNO has organized a one-stop-shop for its customers and partners. Here, the process from idea to mass production with all its players is included, see figure 4. Different partners will contribute to different elements in the chain, where in the end the full contribution will be a complete, customized photonic sensor system.

With its contribution by developing new photonic SOI sensors and setting up the value chain for the sensor system, TNO likes to herald a new era of photonic sensor systems!

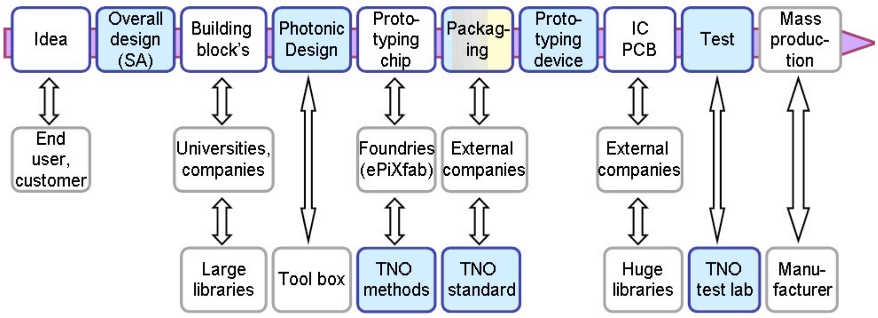

Figure 4: value chain for integrated nanophotonics and the role of TNO (gray)

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