Towards foundry approach for silicon photonics: silicon photonics platform ePIXfab

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Fabless access to wafer-scale silicon photonics technology is moving silicon photonics closer to becoming a mainstream technology and opens up new exciting areas for research at the same time. It is only by using wafer-scale technology that this emerging field will be able to realise its promise: to become a disruptive technology. At the basis of the rationale for silicon photonics is a complex of photonic functions integrated on a single chip, coupled to a stable, high-yield volume fabrication technology base. ePIXfab is a service platform offering R&D oriented access to state-of-the-art 200 mm wafer-scale CMOS technology optimised for silicon photonics purposes.

New areas for research: Silicon photonics opens up possibilities for new research directions as well as innovative products, because of the complexity and diversity it can offer. With its high integration level, at least compared to alternative photonic technologies, silicon photonics can deliver complex photonic ICs. Photonic functionality can be parallelised to a great extent on a single chip, for instance by integrating dozens of telecommunication transceivers, or hundreds or even thousands of biosensors on a single chip. Alternatively, complex circuits with many elements in a single light path can be designed and manufactured, for instance for multiplexing and all-optical signal processing. When combining photonic circuitry with electronic functionality (analogue, digital or mixed-signal) the design space becomes very challenging and interesting. In addition, one might even think of digital photonics, where complexity can exceed that of 'analogue' photonics by an order of magnitude. Research on design and manufacturing of large-scale photonic integrated circuits, a virtually non-existing field today, is therefore necessary to cope with this growing complexity. However, this is only possible if the wafer-scale technology is in place to support such research.

The rationale for silicon photonics is to use silicon as an integration platform. However, its strength is in the way things are designed and fabricated, rather than in the optical properties of the material itself. Silicon is a good material for waveguides [1, 2], but is weak in potential for efficient active electro-optic functions, such as emission. Combining silicon heterogeneously with other materials will lead to applications that we can only dream of today, or we cannot even envision yet. Exciting materials and application research on organics, biomaterials, nanomaterials, metamaterials and compound semiconductors will enter new areas because of silicon photonics. By providing many silicon chips to experiment with as well as novel ideas for characterisation and application, silicon photonics can speed up the turnaround of heterogeneous material-oriented R&D. Then again, design and manufacturing of such heterogeneous chips is challenging: it should be done 'the silicon way' with a high-yield integration approach at the wafer scale.

Silicon photonics ecosystem: Silicon photonics finds its most promising applications in medium and high volume markets such as short-range datacommunication and point-of-care biomedical appliances. Being able to manufacture photonic ICs on wafer-scale is already critical in the development phase of such devices and applications. Furthermore, in order to really enable researchers to move their ideas to a product and component and subsystem providers to explore silicon photonics, there is a need to establish a silicon photonics ecosystem.

Various parts of the food chain are being developed, but currently at a relatively slow pace. The key areas where further development is needed are design software, design, volume manufacturing, packaging, test and standardisation. Note that these are all developments that have been key to the widespread deployment of CMOS electronics. Especially in design and aspects of packaging, further investment in research is needed. Some other aspects of manufacturing, packaging and testing will only be solved in a commercial environment. In addition, concerted action is needed to bring (open) standards to the technology. Such an ecosystem will only grow once there is sufficient commercial interest, but companies will only venture into silicon photonics once there is substantial proof of its potential, which can only be delivered with a significant seed of the ecosystem in place.

These ideas form the rationale of ePIXfab (www.epixfab.eu), the silicon photonics multi-project wafer (MPW) service organised by the research institutes IMEC and CEA-LETI. The mission of ePIXfab is to help solve the chicken-and-egg problem described above, by providing an R&D oriented MPW service to basic wafer-scale technology for silicon photonic circuits, and by supporting R&D and initiatives in design, manufacturing, packaging and testing. The initiative for such joint fabrication of designs by multiple research groups has been taken already in 2002, but IMEC teamed up with LETI in 2006 in the framework of the European ePIXnet Network of Excellence (www.epixnet.org) to offer a more structural MPW service used by worldwide users today. Currently, ePIXfab has processes for both passive and active silicon photonic devices in its portfolio on 200 mm wafers in either the IMEC and LETI pilot line fabs. ePIXfab is now used by users from Europe, Asia and North America, performing research in various fields such as microring resonators [3], photonic crystals [4], signal processing with silicon-organic hybrids [5] and biomedical applications [6].

Technology: In this technology, basic passive building blocks such as low-loss waveguides [2], efficient waveguide crossings [7] and wavelength filter devices for WDM or spectrometry applications [2, 8] were demonstrated and are now integrated in larger circuits. Nonlinear devices for signal processing [5, 9] are actively being studied. Using CMOS processes, active devices are implemented in silicon, or in SiGe integrated in the silicon process flow. With this approach, detectors reaching above 40 GHz bandwidths have been shown [10] as well as high-speed optical modulators based on carrier depletion [11].

Coupling from and to fibre is made easier by using grating couplers, coupling the light to a vertically mounted standard singlemode fibre with relatively good alignment tolerances. Simple (cheap) grating couplers offer around 30% efficiency [12], which is good enough for a lot of lab purposes. For applications such as nonlinear devices, for systems research and for product development, the grating couplers can be optimised to efficiencies reaching 80% or more [2, 13].

This platform is now used for research on heterogeneous devices for a wide range of novel applications based on combining silicon with other materials. By bonding thin III–V material stacks to silicon circuits, we obtained the world's first micro laser integrated on a silicon platform [14], which can also be used as a modulator [15] or wavelength converter [16]. These components are then used for on-chip optical interconnect networks. Another booming research field is that of biosensors, especially label-free sensing, in which tens to hundreds of sensors specifically targeted to certain biomolecules can be integrated on a single chip. By chemically functionalising the silicon surface of a very compact ring resonator device and adding bioreceptors, biomolecules can be specifically bound to a certain resonator [6] and their presence can be detected as well as concentration and flow rates in fluid, even if only very small droplets of the biosamples are available. This has applications in drug development and point-of-care diagnostics, for instance for immunoassays, blood analysis and DNA/RNA analysis.

Disruptive technology: Silicon photonics is a potentially disruptive technology in the sense that while existing products in the market are competing on performance, silicon photonic products will enter the market with lower performance but with lower cost, size, weight and/or power requirements, and change the market dramatically. The biomedical point-of-care diagnostic applications are a good example: while the market is competing for high-performance or high-throughput tools that are typically located in labs or major medical centres, silicon photonics based biosensors may enter with very cheap and fast portable devices, which may have lower performance but open up a different market that may change the way medical diagnostics are done.

Even though the first companies are putting early products on the market, there is still a path to go, however, before we can see the reality of this (or not). As described earlier, major progress is needed to offer a full supply chain. Further process technology development is already taking place, for instance in photonic-electronic integration. But the major question is on the business equation. High-end silicon process technology is extremely expensive and only sustainable for commodity and consumer type volumes at extremely low cost, or for medium volumes for less cost-sensitive markets. It is unclear today how the market can really implement this and for which applications. This is for the industry to solve, but with our MPW access scheme for fabless R&D, we hope to contribute to the impressive technology R&D and business seeds that are being put down by researchers around the world today.

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