Silicon Photonics: an Enabler for Fundamental Science, for the Internet and for the Life Sciences

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Photonic integrated circuits (PIC's) based on silicon technology have gained considerable importance in the past 15 years and have made the transition from the research lab to the manufacturing fab. The key reasons behind this rapid evolution as well as the potential for a broad range of applications are summarized hereafter.

From a physical point of view the key asset of silicon photonics relates to the usage of optical waveguide devices with high refractive index contrast (silicon: 3.5 versus silica: 1.45). This high index contrast allows to confine light down to a wavelength (in silicon), to make ultra-compact devices (bends, filters, splitters, polarization converters), to make microcavities with record level Q/V, to make use of substantial Purcell enhancement, to implement photonic crystal structures and slow-wave structures, to engineer the dispersion properties of waveguides by tailoring their geometry at the nm-level, to make metamaterials based on sub-wavelength structures, to exploit the strong Kerr-effect in silicon e.g. for frequency comb generation, etc. Because of this there has been a "wealth" of achievements in the research community in which a wide variety of physical phenomena have been demonstrated by means of a silicon optical chip, in some cases in a way that is not possible in any other technology.

None of this would have been possible without the mature technological environment of CMOS-fabs. The patterning capabilities in such fabs, relying on 193 nm deep-UV lithography on 200 or 300 mm wafers, allow to fabricate structures with smallest features well below 100 nm, smallest pitches in periodic structures of the order of 100 nm and geometrical precision of the order of a few nm. That is exactly what is needed to implement high-index-contrast nanophotonic devices with good quality and reproducibility, operating at "telecom wavelengths" (1.3 and 1.55 μm) where silicon is transparent.

But the main driver for silicon photonics has been the need from the application side. The rapid growth of the internet has created a large need for high bandwidth optical transceivers with low cost and low footprint for use in short-reach interconnect in data-dense infrastructure. This is where silicon photonics excels, since it is possible to implement optical modulators and detectors for data rates up to 25 and even 40Gb/s and do so with the standard toolbox of processes in an advanced CMOS-fab. It is true to say that up to today it is still not possible to integrate lasers in the transceiver PIC's by means of wafer-scale fabrication processes, but there is a rich variety of hybrid and even partly wafer-scale approaches to integrate III-V semiconductor based laser diodes onto silicon PIC's. Furthermore there is promising scientific progress on truly monolithic approaches for such integration.

A system consists of more than just a photonic chip. The chip needs to be packaged and integrated with other functions, in particular electronic functions. Furthermore with the growing complexity of silicon photonic IC's the need for hierarchical design tools has grown. Over the past years the chain of capabilities and tools for these "auxiliary" methods has gained considerable industrial momentum.

With the technology of silicon photonics gaining maturity there is a tendency to start considering it as a generic technology that can serve a diverse range of markets, not only in datacom and telecom, but also in sensors, biosensors and biomedical instruments. The driver is always the same: create compact and low-cost integrated circuits with a functionality and performance at par with otherwise bulky and costly implementations. Examples of this trend include PIC's for sensing bioparticles such as proteins and DNA, PIC's for spectroscopic detection of various small molecules (glucose, ammonia, markers for food spoilage etc), PIC's for optical coherence tomography or for laser doppler vibrometry, PIC's for readout of fiber Bragg gratings etc.

In those new applications the "traditional" wavelengths of silicon photonics (1.3 and 1.55 μm) are not necessarily optimal from the application's point of view. This has led to the recent trend to "translate" silicon photonics to other wavelength domains, as much as possible without shying away from its major asset which is to fabricate the chip in a CMOS fab. Many groups are pushing the frontiers of silicon photonics towards longer wavelengths (mid-infrared), mainly driven by the promise of using the technology for vibrational spectroscopy. In parallel other groups are pushing towards shorter wavelengths, so as to be more compatible with biological media, fluorescent markers and Raman spectroscopy. In this case the silicon core needs to be replaced by a material that is transparent in the visible, silicon nitride being a good candidate. In those applications silicon itself changes hat and becomes the near-perfect material for detection.

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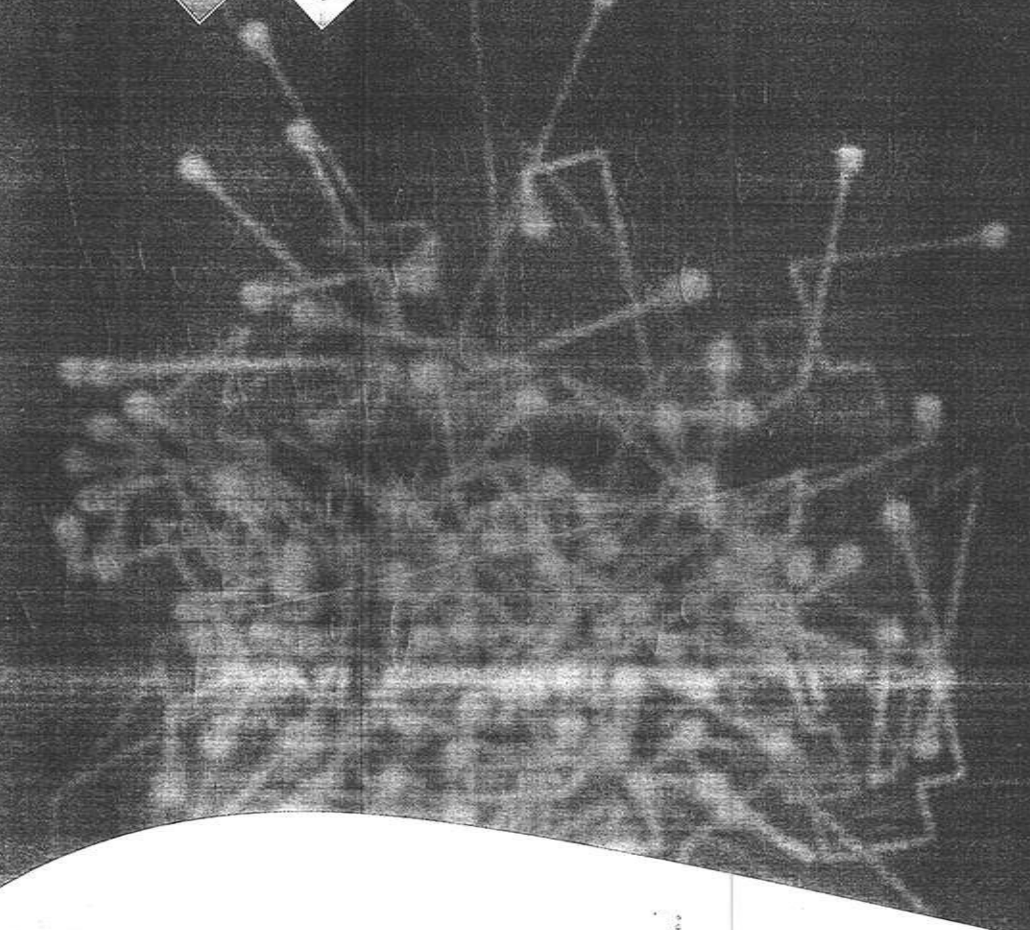

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