SILICON PHOTONICS PASSES THE TIPPING POINT

With its immense potential for cost-effective transformation of optical communications and data management, silicon photonics is coming of age, finds **John Williamson**

Although presently a rather modest business, the production and use of silicon photonics has major commercial potential. According to a study from BCC Research, the global market for photonic integrated circuits could increase from $539 million in 2017 to $1.8 billion in 2022 at a CAGR of 27.5% for the period.

"Silicon photonics has been under development for years, but there are still only a few products on the market," says Dr. Eric Mounier cofounder of the French market research company Yole Développement. "However, now that this technology is being pushed hard by large webcom companies like Google, Amazon, Facebook, or Microsoft, we believe we have reached the tipping point that precedes massive growth."

NEED FOR SPEED

A primary driver for silicon photonics development and deployment is the seemingly endless requirement to build higher capacity, faster networks and networking. "Big data is getting bigger by the second. Transporting this level of data with existing technologies will soon reach its limit in terms of power consumption, density, and weight," argues Dr. Mounier. "Photons will continue replacing electrons throughout networks, including in the data centre, the rack, and very soon on the board."

The need for more speed is increasingly acute in data centre operations. "Data centre traffic growth is driving the need for high-speed connectivity between servers and switches," points out Robert Blum, Strategic Marketing and Business Development Director for Intel's Silicon Photonics Product Division. "Given the scale of data centres, most of these connections require optical links, and this is driving an unprecedented demand for 100G transceivers today to alleviate existing networking bottlenecks.

As an example of what could be in prospect from a capacity standpoint, Frost & Sullivan TechVision Research Analyst Naveen Kannan says Wave Division Multiplexing (WDM) devices built by integrating silicon chips with optical fibres are capable of operating independently up to 40 channels, with different wavelengths of light for each channel. "This opens the door for the possibilities of achieving up to 1.6 Tbits/s in high speed data centres in the near future," he suggests.

SILICON MAKES LIGHT WORK

Low power and tunability are other particular attractions of silicon photonics. "Chromatic dispersion is a dominant limitation in data transmission at higher rates as dispersion-limited reach is inversely proportional to the square of the data rate," adds Kannan. "Silicon-based dispersion compensators offer tunability and lower power consumption capability, and can be easily integrated with on-chip photonic devices."

Mounier also notes that silicon photonics offers the overall advantages of a silicon technology such as low cost, higher integration, more functionalities embedded, higher interconnect density, and better reliability compared with legacy optics.

Silicon photonics has significant advances over traditional optics such as wafer-scale manufacturing and test, along with attendant cost benefits. Semiconductor industry packaging and assembly techniques are used rather than custom low-volume optical packages points out Blum. "This fundamentally changes the cost structure of these optical interconnects," he states. "And as data centre traffic continues to grow, silicon photonics will be a key enabling technology to meet future data centre demands, scaling to 400G and more highly integrated form factors."

But while silicon photonics may have substantial technical and operational benefits, there are a number of challenges associated with its wider development and use.

In general, as remarked by Blum, many of the challenges are similar to traditional optics since today's products

PROGRAMMABLE, COMMON ARCHITECTURE SILICON PHOTONICS CHIP DEVELOPED

Researchers from the Silicon Photonics Group at the Optoelectronics Research Centre (ORC), University of Southampton, and from the Institute of Telecommunications and Multimedia Applications (iTEAM) at the Universitat Politècnica de València, have developed what they say is the first photonic integrated chip that enables multiple functionalities by employing a single common architecture.

The chip's behaviour is similar to that seen in electronic microprocessors, where a common hardware is programmed to perform a desired operation. The team's results have been published in the journal Nature Communications.

By programming the internal connections of a single chip architecture, the chip can be configured to perform different functionalities, and could be used in any field susceptible to the requirement of optical or radio frequency signal processing. This includes, for instance, self-driving cars, mobile communications, quantum computing, distributed sensors, sensing monitoring, the Internet of Things, defence, avionics and surveillance systems.

The chip architecture relies on a honeycomb waveguide mesh implemented by properly cascading tunable light couplers. The independent basic coupler configuration allows the definition of flexible interconnection schemes as well as the definition of different optical signal processing circuits.

The chip was designed by both teams, fabricated in the Southampton Nanofabrication Centre by the members of the Silicon Photonics Group, and characterised by the València team.

The main advantage of this approach is that the physical hardware architecture is manufactured independently from the targeted functionality to be performed, which reduces design cost, fabrication and testing iterations.

Once designed and tested, the chip enables the configuration of more than 100 photonic signal processing circuits, of which around 30 configurations have been demonstrated by the team in Nature Communications, resulting in the highest number reported to date.

"This represents a paradigm shift in the field of integrated photonics, from application specific photonic integrated circuits to generic purpose and programmable devices, in the same way as the success experienced by the electronic field in the 1980s," said Professor José Capmany, lead researcher of the València Group.

use industry-standard form factors that don't necessarily take advantage of all the benefits that come with using silicon photonics.

More specifically, Dr. Mounier instances laser sources and packaging. He says that since silicon cannot have a laser effect because of its indirect bandgap, the laser cannot be monolithically built on the silicon die. So, there are different solutions to laser integration. "After years of R&D, Intel succeeded doing wafer-level integration of the laser by bonding an Indium Phosphide (InP) chip (rather) than doing post-processing, so alignment is not so crucial as it will be performed by lithography," he observes. "The second solution is to flip-chip the laser source, but it is a complex process due to low throughput and high alignment accuracy."

When dealing with optics, packaging accounts for a major share of the final component cost, because of alignment issues and the need to integrate different chips in the same package. Dr. Mounier calculates that in semiconductors, silicon accounts for 80% of the cost while packaging is 20%. In optics, it is the opposite as packaging can be as high as 80% of the final cost. "So solutions are currently developed to reduce cost by increasing assembly throughput at high accuracy," he explains.

Standardisation may be another issue. According to Kannan a major restraining factor for the growth of silicon photonics is that standards for developing photonic integrated circuits are yet be universalised. "This has led to an unclear state in the supply side of the value chain as independent original equipment manufacturers are unsure whether their product would be interoperable," he says. This also may have an impact on investment decisions regarding mass manufacturing capabilities.

BUT FUTURE'S BRIGHT

Notwithstanding theses sorts of challenges, the future for silicon photonics certainly looks bright.

As data rates continue to grow, Intel expects to see the integration of optics with networking silicon, either in the form of high-density switches, network interface controllers or FPGAs with optical I/O. "We see the drive to smaller and smaller form factors with lower power per bit, higher bandwidth densities, and lower cost per bit," says Blum.

"Silicon photonics is a market of big promises - especially in data centres and high-performance computing, huge markets that will dwarf all other silicon photonics applications in the near future," predicts Dr. Mounier. "Also, silicon photonics can be seen as an "enabling technology" for other applications, for example sensors, life science, quantum computing, telecommunications, consumer and automotive."

SILICON PHOTONICS: THE NUTS AND BOLTS

As described by Dr. Mounier, silicon photonics is a mix of several technical blocks - optical, but also integrated circuits for processing, MEMS for packaging, copper pillars and so on, and it involves several core components.

These are:

- Lasers at the heart of any optical device. Today's lasers use Indium Phosphide to produce coherent infrared laser light.
- Photons are then modulated to break the light into optical pulses.
- Optical waveguides and other interconnections are necessary to move pulses from one place to another.
- Multiplexers/demultiplexers are used to separate and combine different wavelengths.
- Finally, detectors convert an optical signal into electric signals.


Silicon photonics wafer fabrication at the ORC, University of Southampton, UK.