# Birth of the programmable optical chip

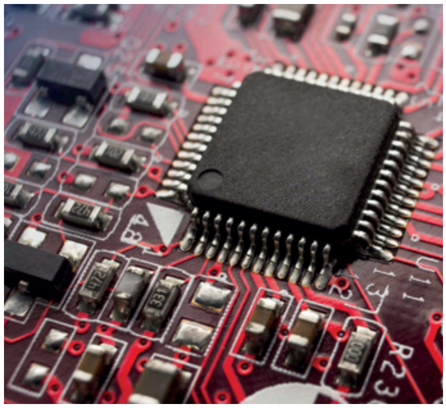
Advances in silicon photonics, compound III–V semiconductor technology and hybrid integration now mean that powerful, programmable optical integrated circuits could be within sight.

The recent acquisition of Altera, the pioneer of programmable logic chips, for US$16.7 billion by the well-known chip maker Intel provides clear recognition of the perceived importance of field-programmable gate array (FPGA) technology. In essence, an FPGA chip is a universal signal processing chip that can be programmed or configured after fabrication to perform a specific task — be it speech recognition, computer vision, cryptography, or something else.

Originally commercialized in the mid-1980s, by two US Silicon Valley firms Altera and Xilinx (who today between them hold an ~80% share of the market), the FPGA chip has grown from humble origins and niche applications to ubiquity. The technology is found inside everything from digital cameras and mobile phones through to sophisticated medical imaging devices, telecommunications equipment and robotics. In the heart of an FPGA is a large array of logic blocks that are wired up by reconfigurable interconnects, allowing the chip to be reconfigured or programmed via specialized software. The use of a standard common hardware platform makes FPGAs far more flexible and cost effective compared with application specific integrated circuits (ASICs) — complex chips that are custom designed for a specific task.

What's potentially exciting is that there are now signs that the optical equivalent of an FPGA is on the horizon. Improvements in both silicon photonics and III–V compound semiconductor technology, such as InP and GaAs, mean that optical researchers are starting to build designs of programmable optical signal processors on a chip by cascading arrays of coupled waveguide structures that feature phase shifters to control the flow of light through the array and thus support reconfigurability. The theory of how such arrays behave has been analysed in depth by David Miller from Stanford University in the US who has published several papers on the topic.

Research teams around the globe specializing in microwave photonics, including Jianping Yao's group at the University of Ottawa, Canada, José Capmany's at Valencia, Spain and Arthur Lowery's group at Monash University in Australia, and others are building



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experimental protoypes with encouraging results. As an example, the News and Views on page 6 of this issue describes an optical integrated circuit composed of a mesh of interconnected Mach–Zehnder interferometers, which acts as a fully programmable filter for radiofrequency (RF) signals.

The prospect of an optical equivalent to the FPGA excites many in the photonics community. "Similar to the invention of electronic FPGAs in 1985, the availability of large-scale programmable optical chips would be an important step forwards towards ultrafast and wide-band signal processing," says Yao. "Currently, digital signal processing speed is limited by the speed of analog-to-digital conversion (ADC). The world's fastest ADC [made by Texas Instruments] can operate at 1 giga-samples per second, which corresponds to a bandwidth of 500 MHz. For a large-scale programmable optical chip, the processing bandwidth can be 1,000 times wider, hundreds of gigahertz."

Yao says that the ultrafast processing capabilities of optical chips could be useful for ultrahigh-speed ADC, all-optical signal processing in communications networks, or fast image processing.

"In principle, the concept of a universal programmable processor should unlock a considerable number of applications," commented Capmany. "For example, in the case of RF photonics this could be RF filtering, arbitrary waveform generation, beam steering, instantaneous frequency measurements, analog-to-digital conversion."

He says that at present, the design of optical circuits to perform a specific task is leading to a situation where there are almost as many technologies as there are applications. This fragmentation hinders cost-effective, mass-volume manufacture of a photonic solution, a situation that an optical programmable chip would help remedy. "It would be a considerable landmark because it would open the possibility of using the same hardware configuration, and thus reduce fabrication costs, to implement different functionalities by suitable programming," commented Capmany.

According to Capmany, the approach could also prove useful in other areas too, such as realizing a multifunctional lab on a chip in biophotonics, reconfigurable logic gates in quantum information systems and software-defined reconfigurable switching and routing fabrics in optical communication networks.

Capmany says that the key decision to be made is the best choice of a material platform for realizing such a chip. "We do have several technologies available but none seem to cover the full range of requirements. Indium phosphide is the only technology capable of providing active elements like lasers and amplifiers. It is certainly the most complete in terms of available components but is quite lossy," he commented. "Silicon brings compatibility with CMOS fabrication processes and low-loss passive components. Unfortunately it is not suitable for implementing optical sources and amplifiers. Finally, silicon nitride provides extremely low losses, which is good for passive components but it is not suitable for implementing active devices, detectors and modulators. It is still not clear if the best solution will be a monolithic or hybrid approach."

Regardless of which platform wins the day, Miller is certainly optimistic about the future potential. "We are really at the edge of a change in the way we think about optics, from thinking in terms of single devices and very simple circuits to systems in which we let a little additional complexity and smartness make the whole system easier to fabricate and operate and much more flexible," he comments. "We went through that transition in electronics some time ago, but we can now start to see how to make that transition in optics as well." ❐