Recent advancements towards all-optical signal processing.

I. Glesk[1*], J. Wang[2], and L. R. Chen[2]
[1]Electronic and Electrical Engineering Dept, University of Strathclyde, 204 George St, Glasgow, G1 1XW, UK
[2] Electrical and Computer Engineering Dept, McGill University, 480 University St, Montreal, H3A 0E9, Canada
[*]corresponding author: ivan.glesk@strath.ac.uk

Abstract-Recent years have seen a rapid growth in demand for ultra high speed data transmission with end users expecting fast, high bandwidth network access. However as data rates increase, present technology based on well-established CMOS electronics is becoming increasingly difficult to scale and consequently optical data networks are struggling to satisfy current user demands. Recently a number of advanced approaches have been reported developed to overcome this bottleneck based on all optical signal processing using silicon photonics devices.

It is becoming evident that the fundamental limits on electronic switching speeds are severely affecting data communications both quantitatively and qualitatively. At present time we do not have any technological solution for immediate implementation to overcome this problem. However, to mitigate this problem a number of approaches have been proposed. One such approach has been the introduction of all-optical processing schemes. It has been also shown that optical signal processing can improve latency, connectivity and scalability of optical networks and interconnects, but undoubtedly its technological implementations are still required to further improve existing processing speed and to take full advantage of the potential serial data rates increases optical networks can offer and support. The requirement for a new disruptive technology is therefore inevitable. Namely, a development of a photonic transistor enabling superfast switching speeds and being compatible with CMOS fabrication techniques would allow much cheaper solutions than developing an all new fabrication technology. Silicon photonics devices can be fabricated using present CMOS fabrication techniques and therefore this technology has been under the microscope for possibilities to develop the future optical signal processing systems.

However, a key missing element for developing the all-optical CPU is a silicon photonic transistor and the supporting optical interconnect technology which is necessary to carry out logic operations and provide the necessary buffering and timing. Some progress in these tasks has been reported and several research groups have been successful in demonstrating what one day may become possible future solutions to this great challenge. For example, Chen et al have demonstrated an optical transistor where a single stored gate photon can control the transmission of applied source photons [1]. However, the transistor is clearly not compatible with CMOS fabrication and since it requires three lasers for the gate and source, and lasers to allow super-cooling of the cesium gas, it is unlikely to provide a practical solution in the foreseeable future. Note, he terms 'gate' and 'source' are used as an analogue to the CMOS FET transistor terminology. Another approach reported by Varghese et al is the development of a silicon optical transistor which uses an asymmetric coupled add/drop filter consisting of a micro-ring resonator next to an optical waveguide representing the source [2]. The device is reported to operate at 10GHz. A notable advantage of this technology is compatibility with current state of the art CMOS fabrication techniques allowing scalability and avoiding the need to develop new fabrication techniques from the ground up. However it is clear that the development of the optical CPU and the all-optical data signal processing is still in the very distant future. Given a future where networks will need to perform ultra-high speed serial data processing all optically there will be basic requirements for all optical Mux/DeMux devices capable of performing at speeds well beyond that are available today.

To overcome the current electronic bottleneck Glesk et al developed a CMOS compatible ultrafast all optical photonic switch [3-4] which does not suffer from the currier recovery time limitations affecting all optical switches based on Semiconductor Optical Amplifiers, SOAs [5] demonstrated previously. This all optical photonic switch has a Mach-Zehnder interferometric structure with one arm composed of a Si nanowire. The second arm is a subwavelength waveguide grating (SWG) structure. Tapered sections are added to properly balance device properties and the loss to help achieve complete interferometric switching.

But there is also a need to develop a library of integrated devices for performing a variety of supporting all optical signal processing functions supporting its application in data centers and elsewhere. One key function required is efficient wavelength filtering. By taking advantage of the ability to tailor the effective index of SWG waveguides, Wang et al [6] proposed CMOS compatible integrated filtering devices (which can also provide an Add/Drop functionality) based on combination of SWG waveguides and/or ring resonators. The biggest advantage for these SWG Bragg grating filtering devices is that the peak reflection wavelength can be tuned very easily by adjusting the duty cycle of the SWG.

In conclusion, optical fibre networks have a vast potential data handling capacity. However this capability is becoming severely limited by serial data processing speed abilities of currently available CMOS electronics. Speed-up using parallel signal processing is confounded by the fundamental limits of Amdahl's Law. This scenario will soon hinder the ability of data networks to scale up to meet exponentially increasing demand for capacity. While all-optical wavelength routing can help improve data network throughput, ultimately at network endpoints any such improvement will be choked by fundamentally limited CMOS electronic signal processing capabilities. Therefore there is a need for the development of a disruptive technology to overcome this bottleneck. A promising candidate is all-optical signal processing. Progress has been made in the development of CMOS compatible photonic devices necessary to achieve this goal. However any further progress depends on speedy development of ultrafast "all-optical transistor" based photonic logic gates.

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