University of Amsterdam

Literatuuronderzoek

Silicon Photonics for Exascale Computing

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Abstract

[Dit gaat ook lekker ruimte innemen]

1 Introduction

Supercomputers are getting ever faster. This increasing speed is measured in FLOPS. Traditionally, achieving each increased order of magnitude of FLOPS has been viewed as a milestone - we achieved one teraFLOPS in 1997, one petaFLOPS in 2008. We are currently well on our way to reaching one exaFLOPS, but we've hit a couple of roadblocks. In this paper, we explore the road towards exascale machines, describe the different challenges and the way they can be solved using silicon photonics.

2 Achieving exascale

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2.1 Why do we need silicon photonics?

Bahadori et al. [2016] note that "the scalability of computing performance is increasingly reliant on the availability of high-bandwidth, energy efficient data communications infrastructure". Coteus et al. [2011] posit that it is necessary to disproportionately increase the amount of computing area on a processor chip, which presents difficulties for memory and networked I/O, unless the balance between memory and computational operations significantly changes or new technologies that can achieve a much larger bandwidth are developed. Rumley et al. [2015] argues that the required bandwidth is likely in the terabit range, which Bahadori and Bergman [2018] argue can be reached using silicon photonics in the form of microring modulators.

As noted in Ho et al. [2013], optical channels provide benefits over solutions using copper wiring:

> *"For data transmission entering or exiting a chip, however, optical channels present an enormous benefit over copper wiring. Optical couplers from on-chip waveguides to silicon interposer waveguides are much smaller than soldered connectors and, with multiple channels per waveguide (wavelength division multiplexing, or WDM), offer much higher net bandwidth. This enables the tight coupling between chips—and concomitant system performance speedup—in a many-chip package."* [Ho et al., 2013, pg. 70]

Apart from these, photonic transmission has more advantages compared to transmission via electric conduction, according to Carusone et al. [2011]. As opposed to copper conductors, photonic fibres are not prone to electromagnetic interference. This immunity to interference, and the fact that fibres do not produce electromagnetic fields themselves, means that there won't occur any cross-talk in big bundles of fibre cables.

3 Silicon Photonics Interconnects and their Structure

[even herschrijven] Jalali and Fathpour [2006]

*The devices silicon photonic interconnects are made of can be divided into 6 categories: **modulators**, **waveguides**, **(de)multiplexers** and **photodetectors**. **Optical modulators** change the phase or amplitude of a light signal, encoding information within it. **Waveguides** guide optical signals along a path from a source to a destination. **(De)multiplexers***

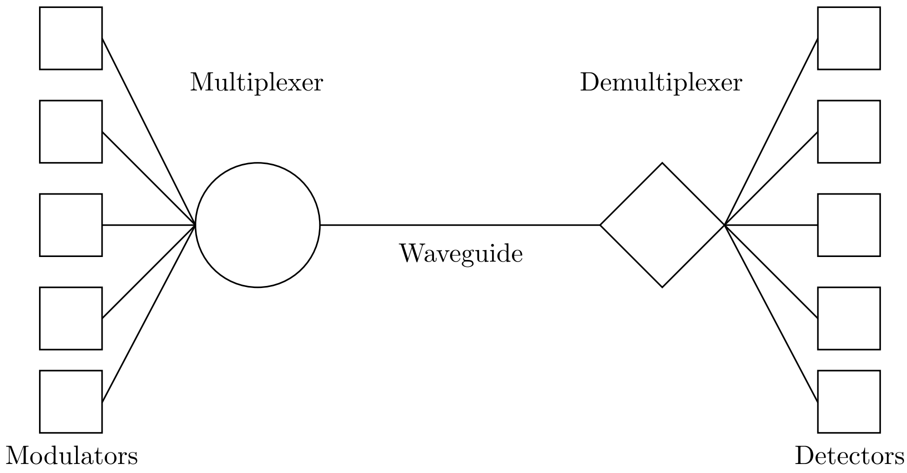

Figure 1: Schematic diagram of the different interconnect components

3.1 Lasers

When trying to transmit an electrical signal using light, a method must be found to convert electrical into photonic energy. Furthermore, as will be discussed in section 3.3, it is necessary for the photonic signal to consist of a homogeneous beam with a single frequency. To achieve this, the light produced by a laser is used as described in Jalali and Fathpour [2006] and Raman lasers in particular as seen in Boyraz and Jalali [2004].

3.2 Waveguides

Waveguides are used to transmit optical signals from a source to a destination. Waveguides guide light through the principle of **total internal reflection**, which means the light reflects off the wall of the waveguides internally, keeping the light confined. Silicon photonic waveguides can be made using a silicon-on-insulator process (see also figure 2) and integrated into customary CMOS processes as described in Rickman [2014] and Li et al. [2012].

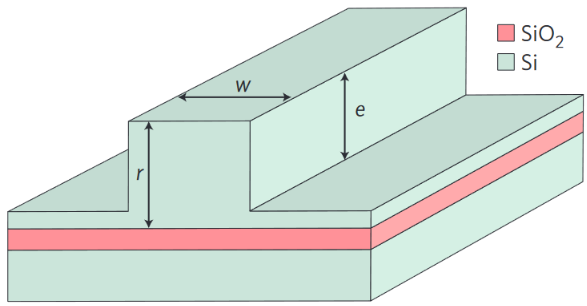

Figure 2: Illustration of a Silicon-on-Insulator waveguide, from Rickman [2014].

3.3 Multiplexers and Demultiplexers

In order to make efficient use of the photonic interconnects, multiple data streams can be send through a single optical fibre.

One of the components which can be used to demultiplex wavelength-division multiplexed optical data is the **silicon microring resonator**. As described in [Bahadori and Bergman, 2018, Bogaerts et al., 2011, section 4 in both], silicon microring resonators can serve as **spectral filters**, filtering incoming light for a given wavelength. Because of this, microring resonators can be chained, as shown in Rumley et al. [2015], to filter multiple wavelengths coming from a single waveguide into wavelength-specific output waveguides.

Additionally, **arrayed waveguide gratings** (AWGs) can be used to both multiplex and demultiplex optical signals, as described in Bogaerts et al. [2006], Rumley et al. [2015] and Cheung et al. [2014]. AWGs operate as shown in figure 3: multiplexed light from the central input waveguide is fed into an input star coupler, which splits the light into the phased array. Due to the difference in length of the waveguides in the phased array, the light coming out of the phased array waveguides has phase shifted depending on the waveguide. This, combined with constructive interference in the output star coupler, causes light of specific wavelengths to be transmitted to each of the output waveguides [Seyringer, 2016]. To multiplex signals instead of demultiplexing them, the output waveguides can simply be considered input waveguides, and the input waveguides considered output waveguides.

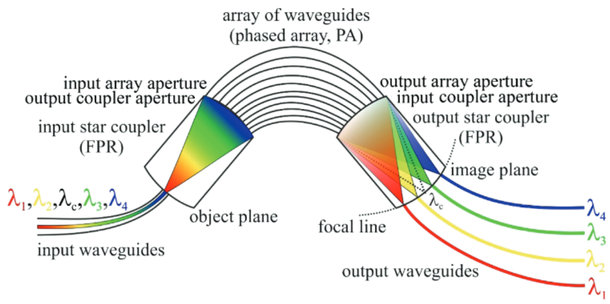

Figure 3: Operation of an arrayed waveguide grating, taken from Seyringer [2016].

Other (de)multiplexer designs have been shown, such as the **Mach-Zehnder lattice (de)multiplexer** in Horst et al. [2013], which claim to be more suitable for use in peta- and exascale computing systems due to their low intra-device losses and flatter transmission pass-bands, which lower the impact of the filters on the optical power budget.

3.4 Modulators

The subsections above all describe devices which make it possible to route optical signals from a source to a destination, where the signal can be detected. For this to be of any use in data transmission, however, we need to be able to encode information in an optical signal. This is what **modulators** are used for. As described in Witzens [2017], this can be achieved through e.g. phase or amplitude modulation. The silicon microring resonators described in section 3.3 can additionally be used to modulate optical signals: [Bogaerts et al., 2006, section 4.4] mentions electrical methods of using ring resonators to perform modulation, and a temperature-based method is outlined in Ho et al. [2013]. Recent advances in modulation methods using microring modulators are outlined in [Bahadori and Bergman, 2018, section 3].

3.5 Photodetectors and Demodulators

The final piece in the photonic interconnect chain is the photodetector together with the demodulator. The photonic signal, transmitted by the components as described above, is of no use to the electrical components of the receiving end without any kind of conversion. This conversion is done by a photodetector. It takes the light signal it receives from a waveguide and converts it to an electrical signal, whilst also demodulating the transmission.

The most common technique to convert photonic energy into electric energy Carusone et al. [2011]

In recent years, a new type of photodetector has been designed. This new variety, as described in Mueller et al. [2010], makes use of graphene to detect photonic signals.

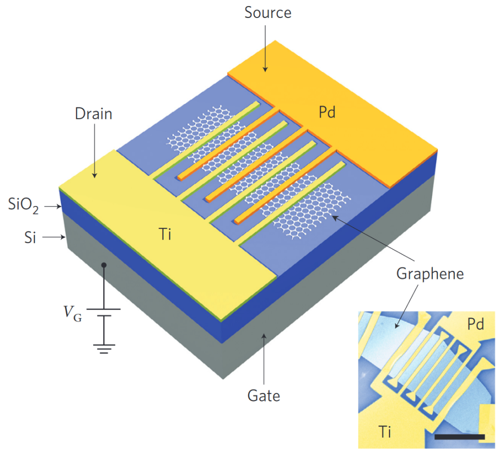

Figure 4: Graphene photodetector as seen in Mueller et al. [2010]

3.6 Additional components

4 Challenges

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