Photonic Integrated Circuits for Data Center Interconnects

Benjamin WOHLFEIL[1*], Danish RAFIQUE[1], Michael EISELT[1]
[1]ADVA Optical Networking SE, Märzenquelle 1-3, Meiningen, 98617, Germany
[*] bwohlfeil@advaoptical.com

Optical transceivers for data center interconnects (DCI) are projected to become a multi-billion dollar market by the end of this decade [1]. Due to the increasing demand for high data rates driven by cloud and mobile applications, next-generation DCIs will not only require higher capacity but also an improvement in bandwidth density, power efficiency and cost. Following the electronics industry's example, where a high level of integration has provided for these goals, the DCI market may also benefit from integration of optical functionality in so called photonic integrated circuits (PIC). In this paper we discuss PIC based solutions for DCIs and explore the challenges for deployment of PICs in DCIs.

DCIs can be categorized into two classes: Intra and inter data center interconnects (see figure 1 for a typical data center network architecture). Intra data center interconnects link individual switches within data centers with data rates up to 100 Gb/s to form a distributed fabric, whereas inter DCIs extend data center fabrics over multiple locations featuring amplified multi Tb/s dense wavelength-division multiplexing (DWDM) links over a single fiber pair.

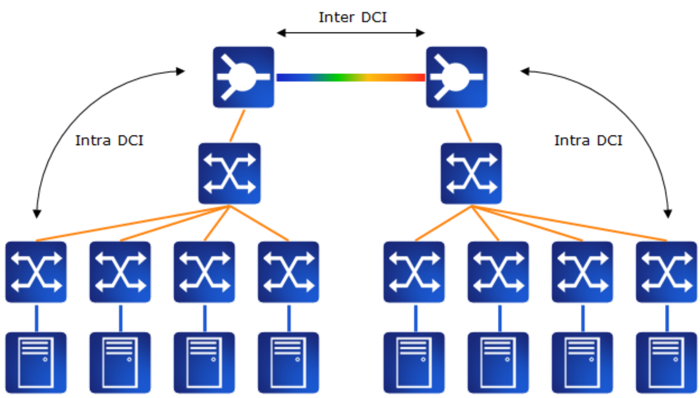

Figure 1: A typical data center network architecture.

Due to the large number of intra DCIs employed in each data center, a significant driver in the intra DCI market is cost – a combination, which highly favors integration. Traditionally, Indium Phosphide (InP) was the material of choice for PICs due to its ability to generate light - a property that is completely absent in silicon. However, silicon benefits from mature fabrication processes giving rise to larger scale integration and high yield. Nonetheless, both technologies suffer from high insertion loss, which is a critical parameter in unamplified intra DCI links, and also from higher power consumption compared to fiber coupled VCSELs, rendering PICs an inefficient solution at low bandwidths (< 10GHz). However, next-generation standards such as 400G Ethernet, which is expected to be ratified by the end of 2017 [2], will require higher line rates, potentially exceeding the bandwidth and signal integrity limits of VCSELs, and thus a need for PIC technology could be seen. Here, InP has the advantage of slightly lower insertion loss compared to silicon since the laser is monolithically integrated on the PIC and does not need to be coupled externally. On the other hand, silicon photonics offers co-integration of electronic and photonic circuits, enabling higher density, better RF performance and lower cost than competing solutions. In addition, a high level of integration facilitates the move to smaller form factors allowing for higher face plate density, for instance compared to current QSFP28 devices.

Inter data center interconnects cover distances of up to several hundred kilometers and thus require amplification. Data rates are as high as 400 Gb/s per wavelength, employing modulation formats with high spectral efficiency such as 16-QAM. Several data signals are multiplexed on a dense wavelength grid with channel spacing down to 50 GHz. Due to the increased complexity on both transmitter and detector side required for coherent data transmission as compared to direct detection, costs are significantly higher for inter DCI transceivers. More sophisticated digital signal processing (DSP) coupled with larger footprint dual polarization coherent optics are the main contributors to high cost for this application. As a recent report shows, despite only a very low percentage of optical integrated components entering the communication market, the revenues generated by those components constitute approximately one third of the global market [3]. Contrary to the claim that PICs are suitable solutions for high quantity low cost applications, this indicates that as of today they are rather high-end products. Technical challenges facing PICs in the inter DCI environment are similar to those in the intra DCI space - with the exception of insertion loss, which plays a less significant role due to the availability of amplification on the transmission line. The increased complexity and tighter operation boundaries of coherent optics compared to direct detection requires a higher degree of control circuitry, e.g. for stabilization of laser emission wavelength or modulator bias points. Accommodating this additional functionality necessitates larger packages and therefore larger form factors such as CFP or CFP2. Recent standardization activities in OIF and the Consortium for On-Board Optics (COBO), however, reflected the industry's desire to move to smaller form factors, necessitating further miniaturization of optical components and therefore benefiting the share of PICs in the DCI market.

An additional challenge PICs are facing irrespective of application is packaging. As no standard solutions are available, as there are for electronic integrated circuits, packaging of PICs is very costly, contributing up to 80% of total device cost. A high degree of automation in assembly and passive alignment of photonic components is required to bring down costs significantly and thus facilitate a more rapid market uptake.

Nevertheless, despite all the challenges PICs are facing, we are seeing an increased employment of integrated optics in the DCI market. However, more effort is needed to further reduce cost, while at the same time scaling capacity, footprint and energy efficiency with market demand.

This work was partially funded by the EU and BMBF through research projects DIMENSION and SpeeD.

References

[1] http://news.ihsmarkit.com/press-release/technology/data-center-optics-market-40g-transceivers-ubiquitous-100g-accelerating
[2] http://www.ieee802.org/3/bs/timeline_3bs_0915.pdf
[3] http://www.lightcounting.com/