Silicon Photonics – Trends, Highlights and Challenges Overview

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The Cisco Global Cloud Index estimates that total data center traffic (all traffic within or exiting a data center) will reach almost 20 zettabytes per year by 2021, up from 7 zettabytes in 2016. Data center traffic on a global scale will grow at a 25 percent CAGR, with cloud data center traffic growth rate at 27 percent CAGR or 3.3-fold growth from 2016 to 2021.

The growth in internet traffic not only accelerates the need for next-generation technology to support higher port density and faster speed transitions but is also accompanied by large physical data center sizes as well as faster connectivity between the data centers. As the data rates and distances to carry high speed data are increasing, the limitations of traditional copper cable and multimode fiber-based solutions are becoming apparent and the industry focus is shifting towards adoption of single-mode fiber-optic solutions.

Silicon Photonics is an emerging technology that is bringing a paradigm shift in the field of single mode fiber-optic communications. Silicon Photonics leverages mature CMOS wafer fabrication and packaging infrastructures to deliver high bandwidth, low power transceivers. Even though the current focus of the industry is to develop products for the pluggable market, it is generally accepted that Silicon Photonics will play a key role in the next generation of optics that is needed for co-packaging with ASICs. [1]

While the primary applications for silicon photonics lie within the data center market, driven by Big Data and cloud applications, this technology is poised to have a large impact within mobile computing as well. There is a need for low-cost optical transceivers to shuttle large volumes of data between wireless cellular antennas and their base stations, often located many kilometers away. Silicon Photonics technology is identified as one of the key technologies needed to provide novel solutions to this new and emerging market space.[2] In addition to data center, telecom and wireless sectors, Silicon Photonics has many other applications. According to a recent Yole market research report, overall silicon photonics market will reach US$3.9 billion in 2025.[3]

This review article focuses on the trends and opportunities in Silicon Photonics for networking applications and highlights some of the challenges that the industry is working collectively on towards making it a mainstream technology.

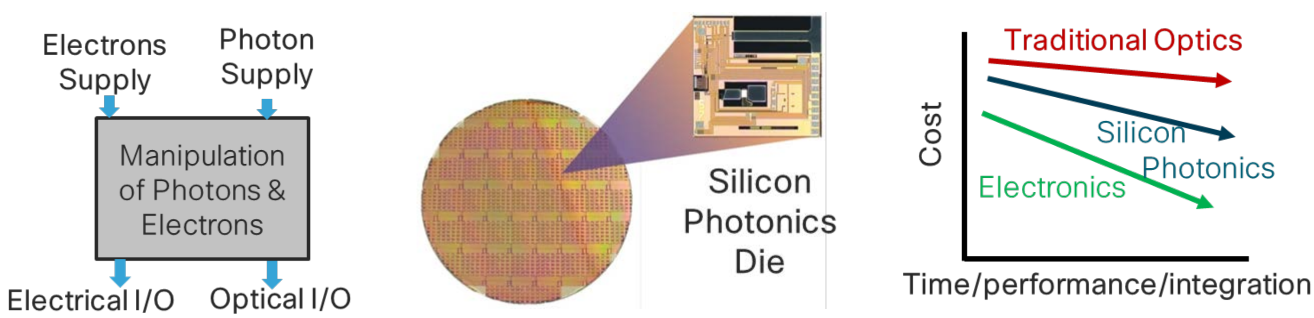
What is Silicon Photonics?

Silicon Photonics is an emerging technology that is bringing a paradigm shift in the field of fiber-optic based communications. Silicon Photonics leverages mature and highly reliable CMOS fabrication and packaging infrastructure and takes advantage of more than 40 years and $400 billion of investment in proven CMOS IC technology, mitigating risks associated with esoteric fabrication technologies.

Silicon photonics technology allows formation of light guiding structures within an SOI silicon substrate and allows guiding, splitting, modulation and detection of light within a Silicon Photonics IC. Except for generation of light, Silicon Photonics can achieve all the remaining functions needed for a transceiver for transmitting and receiving a digital signal to and from a single mode fiber optic cable.

Silicon is a non-direct band gap material, and it is not possible to generate light efficiently in silicon. Hence, a Silicon Photonics IC is typically accompanied with a DC laser light source fabricated using direct band gap III-V materials. The laser source can be remote or can be integrated within the Silicon Photonics IC itself.[4] The photodiodes used for conversion of light into electrical signal (O-E conversion) are made using Ge, a material commonly available in the IC fabrication facilities. The modulation of light (E-O conversion) is typically accomplished by a Mach Zehnder Interferometer (MZI) or with ring resonator design approaches. Fibers are attached to the Silicon Photonics IC to carry light signals in and out of the waveguides of the Silicon Photonics IC using either surface coupling or edge coupling methods (Figure 1a).

One of the key features of the Silicon Photonics is that various optical functional blocks such as waveguides, modulators, mux/demux and detector are implemented using standard layout, DRC, LVS and simulation environment used for integrated circuit design/manufacturing (Figure 1b). Wafer level optical testing infrastructure is also developed by several IC fabrication houses allowing wafer level screening for yield management.



Silicon Photonic IC Transceiver on a Chip

CMOS/OSAT Mfg. Infrastructure

Future of Optics Co-packaging with ASICs

Figure 1: The promise of Silicon Photonics

In contrast to the traditional approach of using discrete optical elements with precision placements and costly alignments, Silicon Photonics enables wafer scale manufacturing of optics with very high level of integration and scalability (Figure 1c). Silicon Photonics can be used in both 1310nm (direct detect- within data centers) and 1550nm (coherent- between data centers and long haul) wavelength categories and can support PAM4 and advanced coherent modulation schemes covering a wide spectrum of products.

Early products based on this technology relied on wire bonding to establish electrical connections between the electrical ICs (Driver, TIA, SERDES) and the Silicon Photonics IC. However, as the data rate and level of complexity have increased, more advanced packaging technologies such as 2.5D integration, TSVs, fanout technologies and 3D integration are being quicky adopted.

Silicon Photonics based Pluggable Transceiver modules

The industry adoption of Silicon Photonics based 100G modules has already started and is expected to accelerate with 400G and beyond. Silicon photonics based direct detect as well as coherent transceivers are being shipped by several vendors and roadmaps to develop Silicon Photonics based higher speed and co packaged optics products have been shared by many companies.[5]

As the network connectivity speeds continue to increase to facilitate the enormous growth in traffic, the industry is witnessing a migration from 10G to 40G to 100G to 400G and beyond leading to higher port density and faster speed transitions. This is accompanied by a higher level of component integration/packaging. The next generation form factors such as OSFP and QSFP-DD are targeted for 400G and 800G direct detect as well as 400G ZR+ coherent products.[6],[7] Silicon Photonics based products are already being shipped or under development for CPAK, QSP28, OSFP QSFP-DD and QSFP800 form factors (Figure 2).

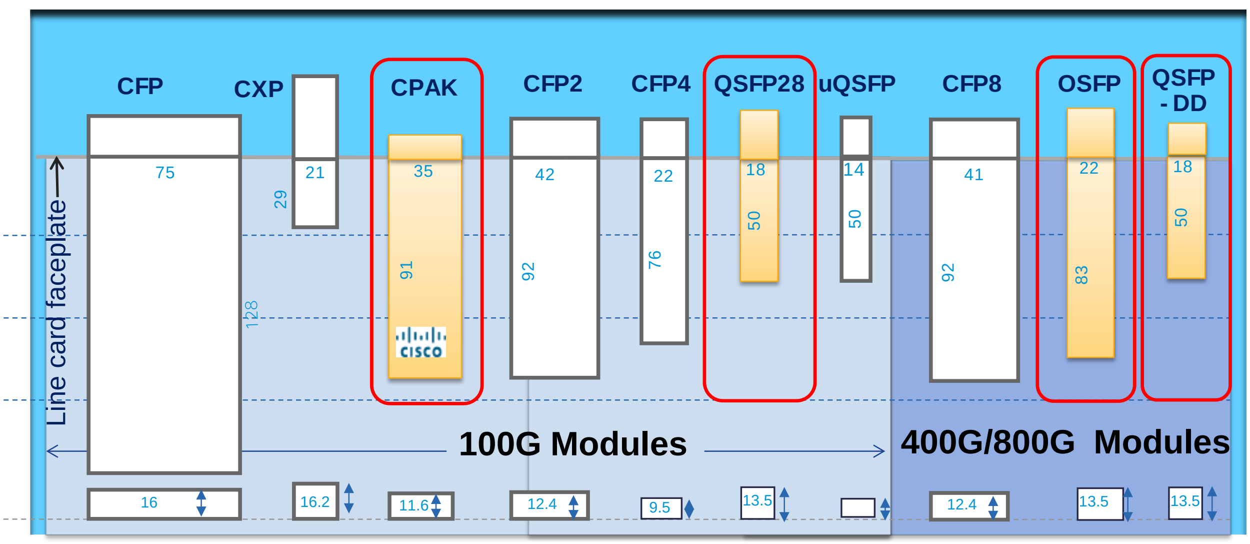


Figure 2: Evolution of Pluggable Modules

Data Center Evolution: From Pluggable to Co-Packaged Optics

ASIC performance continues to follow the Moore's law and doubles every two-three years. ASIC capacity is expected to increase from 12.6Tb to 25.2Tb to 51.4Tb and beyond, requiring corresponding increase in the electrical signal speed of each I/O pin (input/output) and pin density in the ASIC. With each new generation of ASIC, the challenge of moving the electrical signals across becomes much greater as traditional metal wiring reaches its limits. To solve this challenge, the industry is focusing on bring the optics closer and closer to the ASIC. Hence co-packaging of optics and ASIC will become a necessity in the future to assure continued innovation in routing and switching.

OIF has already announced a project to address data rates around 224 Gbps[8] and it is widely believed that 102.4T switch ASIC will use 224 Gbps SerDes interface. According to a white paper by Rambus, integrating 800G optical engines in the same package as the switch ASIC will allow the size, complexity, and power of the 112G SerDes to drop to extra short reach (XSR) requirements(Figure 3). Running at less than 1 picojoule per bit, XSR links reduce the I/O power by more than 80% and the switch ASIC thermal design power (TDP) by more than 25% compared to traditional short reach SerDes running at the same speed. [9]

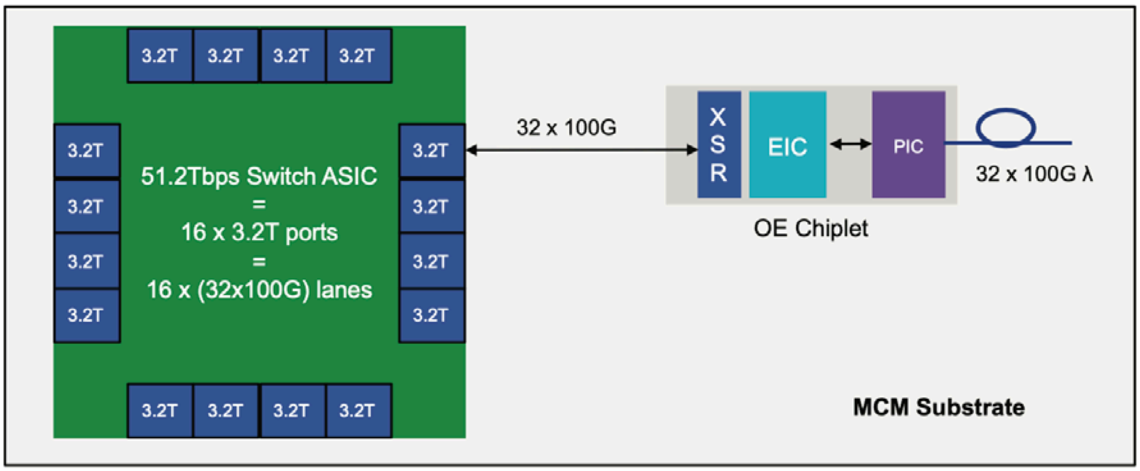


Figure 3 : Co-packaging of 51.2 Tbps Switch ASICS- a conceptual drawing by Rambus

Applications of Silicon Photonics are not just limited to optical communication!!

In addition to optical communication, Silicon Photonics has many applications in a wide range of industries that have the potential to revolutionize the world. These applications include optical interconnects and new architectures for high performance exascale super computers[10], lab on a chip for biomedical testing and drug discovery[11], LIDARs for self driving cars[12], reconfigurable antennas for radars[13] as well as chip scale optical frequency combs for defense applications[14] to name a few. As the technology matures and eco system develops, Silicon Photonics is expected to find many more applications. One of such notable application is development of Silicon Photonics based products for rapid testing and vaccine discovery for Covid-19[15].

JEDEC Initiative to develop standards for Silicon Photonics reliability

While high data rate pluggable modules and co-packaging are exciting developments that brings a confluence of advances in semiconductor packaging such as 2,2.5D,3D heterogeneous integration, optical alignments, thermal management and component and system level assembly schemes and testing, in it lie many challenges as well. These challenges, viewed from a traditional packaging framework, stem from selection of appropriate materials, integration schemes and architectures as well as to quantify and ensure testability and reliability. From the supply chain point of view, the eco system is very fragmented and developing quality and reliability standards is a need of the hour to qualify and manage supply chain handoffs.

By recognizing this need, JEDEC has recently formed Silicon Photonics Qualification and Reliability Standards Task Group (JC14) [16] with the goal of creating Silicon Photonics qualification and reliability standards (guidelines and methodology) within the JEDEC organization. The initial focus of this group is to develop requirements specific to Telecom Datacom. In the longer term, it plans to Include other industries using Silicon Photonics technology such as Automotive, Bio-medical, Sensing, Computing.

Conclusion

In conclusion, the evolving Si-photonics technology offers a large opportunity to utilize innovation in electronic packaging technologies to meet the needs of the market currently driven by data centers, telecom and many other upcoming verticals. This article looked into the trends in pluggable transceiver modules and upcoming trends in co-packaged optics.

EPS Technical committee (TC) on Photonics aims to create a platform for conversation on this topic and would like to invite you to check for activities and updates on its webpage https://cmte.ieee.org/eps-pcsl/. The TC offers periodic webinars on related fields offered by leading industry experts and is a sponsor of the annual Reliability for Electronics and Photonic Packaging symposium https://attend.ieee.org/repp/ .
If you would like to contribute as a member into the committee, kindly contact the chair via *email*.

For details on EPS – Photonics Technical committee, kindly send email to gnyan.ramakrishna@ieee.org

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