CIR
ENLIGHTENED ANALYSIS

Markets for On-Chip and Chip-to-Chip Optical Interconnects 2015 to 2024

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Chapter One: Introduction

1.1 Background to this Report

CIR's last report on the chip-level optical interconnect market was published in 2013, following one in 2010. This volume brings the story up to date with the latest developments in chip-level optical interconnection, an area that is developing fast; indeed accelerating as the semiconductor moves through process nodes.

The key drivers for optical interconnection in all parts of the network are the same whether it is chip-to-chip/ on-chip sector or rack-based/ board-to-board sector. All the sectors have some common drivers such as faster processors, more video, big data, clouds, faster I/O and networks, and so on.

And the need for optical interconnection at the chip level appears to be growing more intense. The so-called "interconnect bottleneck" continues to create opportunities for optical device and cable makers or all kinds. This need is increasing with each new node; in high performance processors with metal tracks, clock distribution alone can use up to 50 percent of total chip power.

1.1.1 Markets for Chip-Related Optical Interconnection: Players, Products and Opportunities

So far, chip-level optical interconnect has taken on the form of enabling technologies rather than sources of revenue generation. However, we think the powerful market drivers will start to change this situation and firms active in this space will start to look increasingly at chip-level optical interconnection as a profit center.

Those interested in this space are very diverse\—they vary from giant multinationals with huge R&D budgets and related product lines (e.g., IBM and Intel) to smaller firms that compete with novel technology development. CIR believes that over the next few years, there are going to be a lot more of the latter as R&D turns into real products and processes. Meanwhile, CIR continues to notice that companies producing materials are beginning to show considerable interest in optical interconnection. Among other things, the interest of these companies in optical interconnection at the chip level is the prospect for polymer waveguides in chip-level optical interconnection.

There is also some interest in devising specific components—and sub-components—for chip- level optical interconnection. Here we are talking about everything from micro-lenses to new kinds of miniature lasers. However, much of this work seems to address broader markets than just optical interconnects, which are only one of the interests of the component suppliers. This is also somewhat true of firms that are focused on optical integration, including the use of high-priced compound semiconductors (principally InP) and also silicon photonics.

Still, interesting things continue to happen in the optical integration space with regard to chip-level interconnect. For example, as we have reported before, efforts to form a photonic interconnect using a single epitaxial growth step have confirmed that it is possible to use Germanium quantum-well interconnects for low-voltage, broadband optical links integrated on silicon chips. It is also possible to extend it to any similar optoelectronic device.

We believe that there is also a growing interest in interconnects using carbon nanotubes (CNTs) and we have seen some technical papers on this topic appear in 2014. CNT interconnects are potentially a threat to chip-level optical interconnection, but this threat is not likely to manifest itself for quite some time to come.

1.1.2 Optical Engines and Backplanes: Immediate Revenues from Optical Interconnect?

The immediate prospects for revenues in this space continue to come from miniaturized optical assemblies or optical engines as well as optical backplanes of various kinds in the category of sub-systems. Optical engines are mostly sold at the present time mostly for board-to-board and some chip-to-chip communications. However, CIR expects them to be further miniaturized in the next few years and we don't doubt that today’s optical engine technology will inspire future on-chip interconnection to some extent.

Optical engines: In the context of this report we refer to miniaturized optical assemblies when we discuss the "optical engine". In the larger context, optical engines have a number of different meanings. Companies like Avago, Finisar, Kotura, Reflex Photonics and Samtec are quite prominent in this space and the report outlines further their efforts in this market.

We expect optical engines to be an important element in this market from a business standpoint due to the fact that they offer something close to being an off-the-shelf solution to board firms. One open question is: How will the architectures of these devices and materials used change as device dimensions shrink and what is the revenue potential of optical engines over the next ten years?

Optical backplanes: Important firms such as Cisco and Juniper have taken steps toward deploying optical backplanes. In CIR's opinion optical backplanes are no longer just a topic of academic discussion and have come into the mainstream of technology implementation.

Optical backplanes can be implemented in a number of ways. These include the simplest conceptual implementation where electrical wires are replaced with EO-converters and waveguides. This approach requires the least re-design. But a fully optical backplane represents a more complete solution and here the optical backplane becomes the complete equivalent of an electrical backplane but with optical chips.

1.1.3 Emerging Technologies for Chip-Based Optical Interconnection: Long-Term Opportunities

Optical engines and optical backplanes represent only the beginning of optical interconnection at the chip level and in the years ahead we expect innovations to happen in this sphere that will take optical interconnection to a point where it can function on a chip. Considering the market and the technology, CIR believes that there are three promising enabling technologies that could help here.

Silicon photonics: Silicon photonics is really just a form of optical integration, which uses CMOS technology designed for the semiconductor industry as its basis. Silicon photonics is based on the vast accumulated knowledge of silicon physics and this technology makes it easy to create hybrid optical/electrical chips. The introduction and development of silicon photonics forms the basis of optical interconnection at the chip level. Silicon photonics would represent a major step since it would allow optical devices to be built into a monolithically integrated chip along with electronic functionality, making optical interconnects almost free.

Silicon does not have the ideal optical properties to lend itself easily to making optical components in commercial quantities. Though silicon waveguides are nonetheless already commercialized the big breakthrough in this technology is still awaited and it is expected that these will be in active components using silicon, when they do happen.

At present, the use of silicon photonics to build lasers remains speculative and the commercialization of such lasers remains a plan and expectation rather than a reality. The development of silicon lasers would be a major step forward and when they do happen, they could enable the development of a transponder-on-a-chip. Such an event would be a truly revolutionary development.

Meanwhile, there is plenty of progress in the development of silicon waveguides, but none of it could be considered revolutionary. For example, silicon waveguides have been made from silicon fibers insulated with silicon dioxide. For obvious reasons, Intel has always been a force to be reckoned with in this space.

In the last two-three years, however, the company has not given much prominence to its silicon laser efforts, compared to its efforts earlier. Intel's recent effort has been to demonstrate the feasibility of directly integrating photonics with silicon CMOS in its prototype form, but for this to become a widely used solution will require some type of advanced packaging, such as flip-chipped lasers. Intel's demonstration in partnership with Fujitsu of the world's first Optical PCIe Express (OPCIe)-based server is seen as a first step in the direction. Because of the inherent potential for integrating optics into electronics with silicon photonics, a technological breakthrough in this area may lead to a huge expansion of the opportunities for optical interconnection at the chip level as a whole.

Other kinds of optical integration: What is more likely is that more conventional forms of optical integration might be required to take optical interconnection forward if silicon photonics does not make much headway in the short term. The kind of material used in optical integration qualifies the technology and process. Most optical integration uses the usual compound semiconductors that are associated with active optical devices; notably InP.

Active optical components can be combined with silicon devices to create new forms of hybrid integration to produce similar functionality to the silicon photonics devices. However this adds to the cost of the final device. At present the positive factor is that the photonics community has a much clearer idea of how to produce this kind of hybrid chip than the active silicon photonics chip just mentioned.

Whatever approach to optical integration is used, it will also be required that optical integration adapt to the latest trends in ASICs, FPGAs and chips more generally. In particular, as CIR sees it, the commercialization of CMOS-compatible optical interconnection using 3D architectures and other solutions seems to raise new opportunities and challenges for optical interconnection.

Quantum dot lasers: Quantum dot lasers represent the far end of the technology landscape and are something of a long shot at present. However quantum dot lasers seem well suited for certain kinds of interconnection and they have been available commercially for about four years now. QD-enhanced VCSELs have also been proposed and these, too, may have applications in interconnection.

However, there is little doubt that commercial chip-level interconnection using QD lasers is a long way off. We note, however, that in the past year, a considerable amount of success has been achieved with QDs for displays and some of the work in this area may rub off on QD-laser interconnection.

1.1.4 Closing Thoughts on the Chip-Level Interconnection Supply Chain

Finally, we note that the primary role that CIR expects integration to play in the chip-level interconnect space could have some interesting implications for the supply chain, which is currently based on a clear separation of the transceiver/optical components space and the chip space.

CIR thinks this can be resolved in a couple of ways. In the short term, what seems to make sense is for the chip sector and the optics sector to cooperate more fully through business ecosystems. However, we suspect that if optical interconnection at the chip level becomes common, something more structured will be needed, opening up the interconnect sector for specialized start-ups and acquisitions.

With regard to the latter, the firms that are most likely to be doing the acquiring are the large semiconductor firms that have the resources to make such acquisitions and have sufficient financial resources to adopt long-term market strategies for such niche businesses. We suspect that the timeframe for this kind of structural change is two to five years, but that 2015 may be the year in which this transformation begins to take off.

1.2 Objectives of this Report

In this report, CIR analyzes both the latest commercial developments in optical interconnection at the chip level (both on-chip and chip-to-chip) and the progress in this area that is being made by important research teams worldwide. The coverage includes an investigation into the very latest architectures, devices, and materials that are impacting the prospects for on-chip and chip-to-chip optical connection.

Given all the interesting developments outlined above, the goal of this report is to identify the opportunities that are emerging as a result. Where possible, we have also quantified these and projected them forward over the next few years, based on an in-depth analysis of the optical interconnect market at the chip-level. Based on this analysis, the report identifies the opportunities in this space for makers of optical assemblies, PCBs, backplanes, lasers, waveguides, fiber and other photonic components and materials.

This report also contains a 10-year analysis that quantifies where and when the commercial opportunities for optical interconnection at the chip level will emerge and how much they will be worth. We also profile the leading firms and research efforts involved in designing and implementing on-chip and chip-to-chip optical interconnection.

From a geographical perspective this report is worldwide in scope. A companion volume covering optical interconnection at the rack- and board-to-board level is also available from CIR. Although the needs and maturity of these two market sectors are different, they often share technologies and technological trends.

1.3 Methodology and Information Sources for this Report

The research methodology for this report is based on both primary and secondary research. The primary research consists of interviews with leading firms active in this space, with these interviews covering both technical and marketing issues.

Extensive secondary research for this report was accomplished by reviewing many sources. These information sources included research journals, SEC reports, standards bodies, trade show and conference material, corporate websites and previous CIR reports.

CIR has been forecasting developments in the optical telecom and data communications business since 1985. The details of our forecasting methodology for this report are provided in the main body of the report.

1.4 Plan of this Report

Chapter Two of this report provides an analysis of the potential demand for on-chip/chip-to-chip interconnection, examining the main factors that shape—and will shape—the commercialization of chip-level optical interconnection.

Chapter Three reviews the current and future technologies that are emerging for chip-level optical interconnection, examining both developments in optics and electronics that are relevant to this opportunity.

Finally, in Chapter Four we provide 10-year forecasts of the markets enabled by chip-level optical interconnection as well as a related discussion on optical integration technologies.