The 50G Silicon Photonics Link

The world's first silicon-based optical data connection with integrated lasers

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Executive Summary

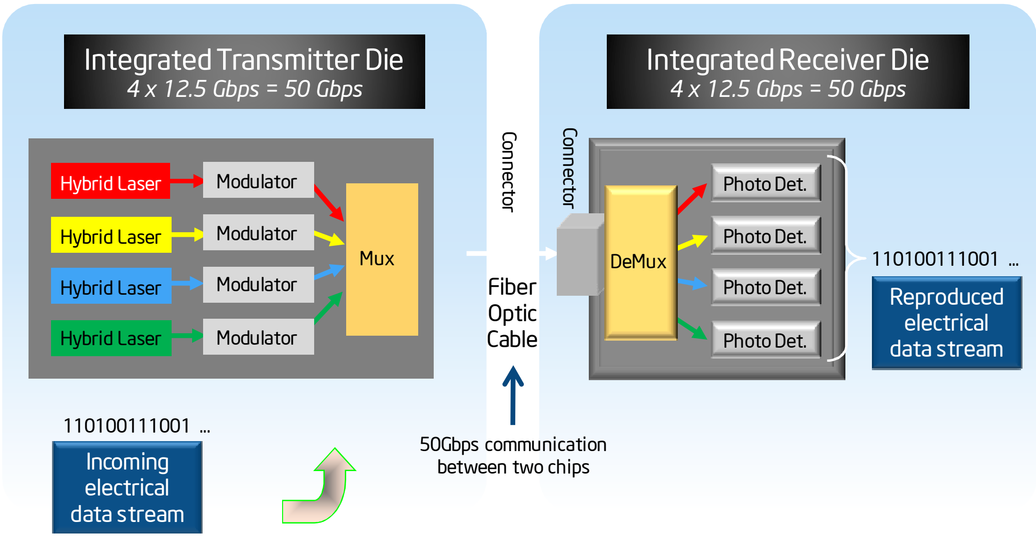
As information technology continues to advance, wire-based connections are nearing their limits of bandwidth and distance. Intel researchers have demonstrated their latest breakthrough: the world's first silicon-based photonics link running at 50 Gbps, with Terabit speeds on the horizon. In combining the unique attributes of fiber-optics with silicon manufacturing processes, the 50G Silicon Photonics Link represents a major advance toward ultra-high bandwidth, low cost, optical communications, which will fuel the design and development prospects of forthcoming data center, business and consumer applications.

Introduction

Information technology (IT) continues to follow Moore's Law of perpetually advancing computational performance within systems and devices. With an increasing number of cores, integrated circuits (ICs) have maintained their progression of data-crunching capabilities. This is enabling the creation and advancement of everything from scalable cloud datacenters to new high-performance computing (HPC) applications to more powerful consumer devices.

While computing systems in general and their central processing units (CPUs) in particular continue to experience performance gains, the connections between them are nearing their physical limits. The current tactic of adding an exponential number of cables to integrate and support a computing environment has resulted in performance bottlenecks, thermal and airflow issues as well as maintenance and cost ramifications. And forthcoming computing requirements will exceed the capabilities of copper-based links, the longstanding means for connecting systems and transporting data into and out of CPUs. While wired connections will always have a prominent role within and between computing devices, certain systems and applications will soon demand interconnects that support greater bandwidth across longer distances.

2010 marks the 50th anniversary of the laser and 51st anniversary of the IC. The best aspects of these revolutionary technologies that shaped the latter half of the 20th century are now being combined to fuel the prospects of innovation for the 21st century. By bringing together the high speed, long distance communication attributes of lasers with the low cost, scalable manufacturing process of silicon, Intel Labs' Silicon Photonics researchers are setting the stage for the performance, communication and design possibilities of tomorrow's technologies.



Beyond discrete laser manufacturing
Lasers have had a remarkable impact since their conception in 1960. Delivering extremely high bandwidth across lengthy spans, they have facilitated the explosive growth of the Internet and modern telecommunications, while influencing everything from biomedical and manufacturing applications to consumer devices such as DVD players.

Despite their notable advantages of bandwidth, distance and accuracy, lasers have traditionally been cost prohibitive for most applications. Needing precise alignment, they are typically developed and assembled individually, mechanically placed and attached using discrete methodology. This has rendered lasers impractical for high-volume business and consumer applications.

By integrating lasers with silicon, however, developers can take advantage of the high volume, low cost and broad scalability of silicon manufacturing processes. Driven by Intel Labs' Silicon Photonics research teams, these developments represent a major advancement toward cost-effective, highly integrated optical interconnects running from 50 Gbps to Terabit speeds.

From breakthroughs to building blocks

Today's silicon photonics achievements are the culmination of several Intel breakthroughs. Ever since the first 1 GHz silicon modulator was announced in 2004, foundational technologies related to hybrid light sources, advanced modulation, light guidance and photo detection have been developed and refined. These are the building blocks that have made integrated silicon photonics devices possible.

Notable Intel breakthroughs include:

- February 2004: world's first 1 GHz silicon modulator
- February 2005: world's first continuous wave silicon Raman laser
- April 2005: world's first 10 Gbps silicon modulator
- September 2006: world's first hybrid silicon laser
- July 2007: world's first 40 Gbps silicon modulator
- August 2007: world's first 40 Gbps PIN photodetector
- December 2008: world's first 340 GHz Gain*BW avalanche photodetector (APD)

A fully integrated connection

Utilizing these building blocks, Intel researchers have developed the first complete silicon photonics data connection: the 50G Silicon Photonics Link. Instead of metal or copper wires, it uses lasers to send light rays across optical fibers, transporting data between two silicon chips at extremely high speeds, across sizeable distances and with relative immunity to noise.

The complete link includes two silicon chips, a transmitter and a receiver, with all the necessary optical technologies from previous breakthroughs. It is composed of four optical channels, each running at 12.5 Gbps, which are combined onto a single fiber to transmit data up to 50 Gbps (see Figure 1).

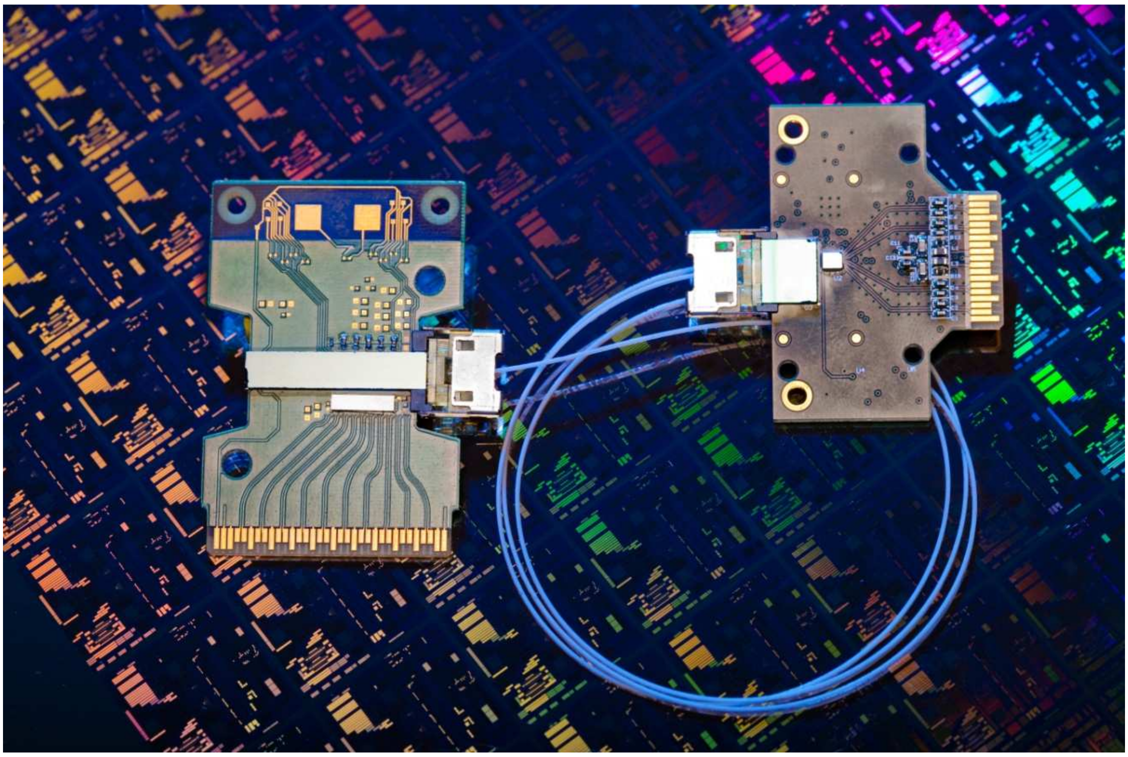
Four hybrid silicon lasers, which act as the light sources, are the key enablers of the link. Hybrid silicon lasers are created by fusing a layer of Indium Phosphide onto the silicon waveguides during the manufacturing process. Because this fusion is done at the wafer level, discrete laser assembly and alignment are not required. This reduces manufacturing complexity, boosts coupling efficiency and allows thousands of lasers to be created at one time on the silicon wafer.

While traditional, discrete lasers have required direct modulation – resulting in performance limitations – the 50G Silicon Photonics Link utilizes integrated silicon modulators with much more performance headroom. Using constructive and deconstructive interference, the high speed modulators act as downstream "shutters" that place data onto light from the hybrid lasers.

A downstream, passive multiplexer (mux) combines the four light streams and their associated data onto a single fiber optic cable, or waveguide. At the other end of the link, a demultiplexer (demux) and set of four photodetectors on the integrated receiver chip collect the light and convert it into an electrical data stream.

The Integrated Silicon Photonics Link adheres to the following steps of operation:

1. Generate light at distinct wavelengths
2. Transform electrical signals into photonic signals
3. Multiplex photonic channels onto single fiber
4. Separate photonic channels
5. Detect photons and convert back to electrical signals



A 50Gbps Silicon Photonics transmit module (left) sends laser light from the silicon chip at the center of the green board travels to the receiver module (right), where a second silicon chip detects the data on the laser and converts it back into an electrical signal

Benefits

The 50G Silicon Photonics Link brings together the unique attributes of laser and IC technologies. A single set of transmitter and receiver chips can deliver 50 Gbps bandwidth over long distances, with extremely low error rates. Bandwidth can "scale up" in modulation speed and "scale out" by integrating more optical channels into the link, providing a clear path to Terabit I/O connections.

Modulator Speed (Gbps)	Number of Channels	Data Rate
12.5	x4	50Gbps
12.5	x8	100Gbps
25	x16	400Gbps
40	x25	1Tbps

Scaling speeds for the future

Because it is developed using silicon manufacturing methodologies, the link can be utilized for high volume applications with minimal process complexity or cost. And instead of active alignment between the chip and fiber, the link takes advantage of passive packaging. This eliminates the need for discrete manufacturing and alignment, dramatically reducing the time and cost of assembly.

Intel's silicon photonics technologies will fuel the prospects of hardware innovation, enabling developers to:

- Increase bandwidth in multiple directions, from 50 Gbps to tera-scale levels
- Realize cost-effective deployment across multiple applications

Applications

The system and application possibilities of silicon-based laser interconnects are nothing less than transformational.

Today, systems must be self-contained and components must be closely positioned due to the bandwidth and distance shortcomings of wire-based connections. Low cost fiber-optics will allow computer makers to completely rethink traditional system designs. By separating processing, memory and graphics capabilities, designers can move beyond discrete computing systems to deliver greater processing capabilities to a wider array of devices and computing environments. This design flexibility will positively influence energy efficiency, systems performance and the cost of development and ownership on a broad scale. It will also fuel widespread innovation and the advancement of:

- Computing applications, from Gigabit to Terabit
- Cloud datacenters
- Throughput intensive applications in scientific computing
- Ultra-high resolution 3D applications for future consumer electronics

Summary

Intel researchers have demonstrated the world's first end-to-end data connection using integrated hybrid lasers. Built on Intel's breakthrough silicon photonics technologies, the 50G Silicon Photonics Link moves massive amounts of information by fiber optics instead of wires.

Extremely thin and light optical cables carry data at rates of 50 Gbps in and around computers over long distances, with researchers now pressing on to higher speeds.

By integrating lasers with silicon manufacturing processes, the 50G Silicon Photonics Link combines the unique attributes of optics and silicon. High speed, long distance communications are now within reach for low cost, high volume applications. These developments will have a transformative impact on the entire computing industry, from data centers to business applications to consumer devices.

Learn more

For more information about the 50G link, visit www.intel.com/go/sp

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