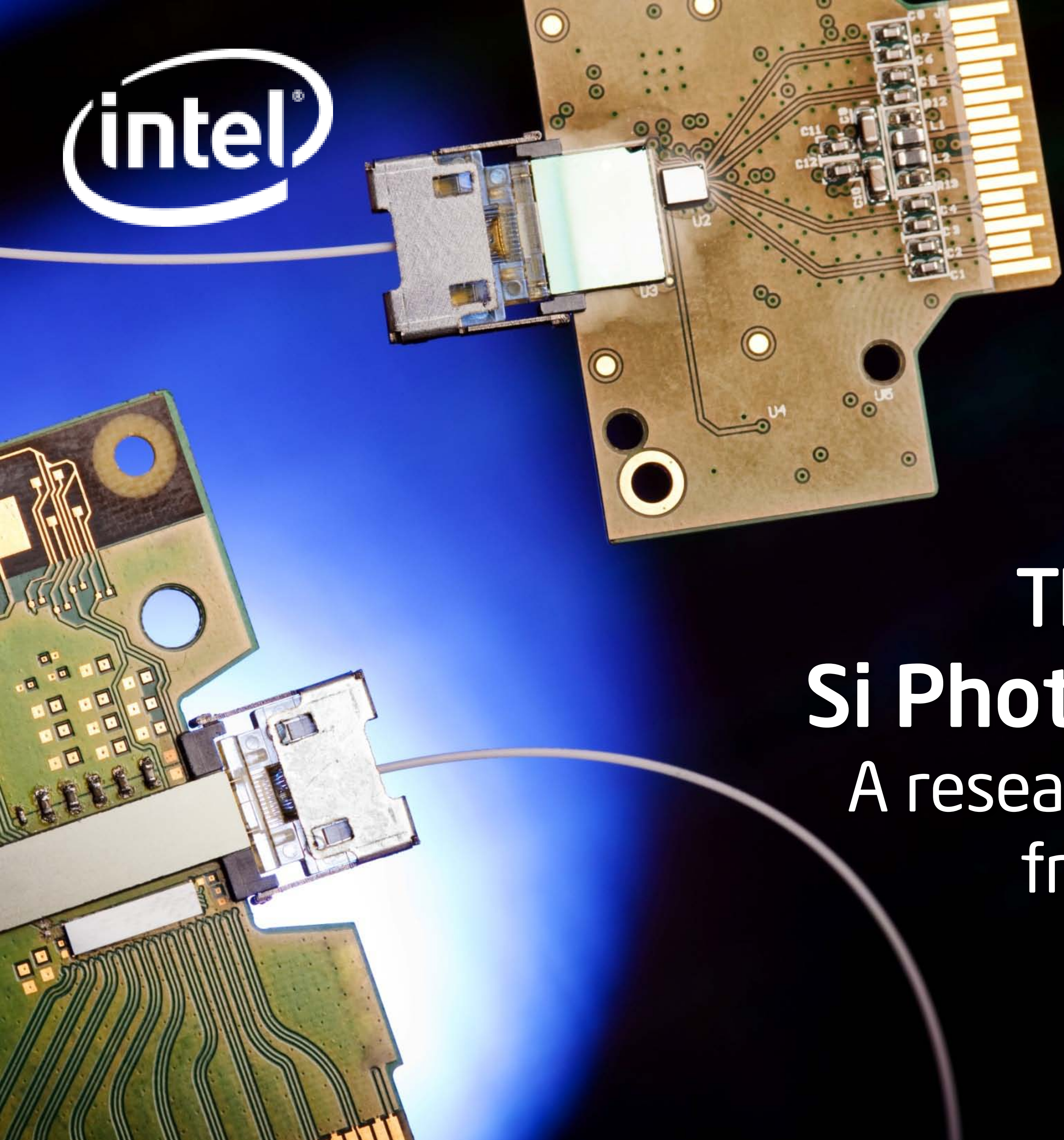

The 50Gbps Si Photonics Link

A research milestone from Intel Labs

Today's Agenda

Today's News and Impact

Mr. Justin Rattner

Intel Chief Technology Officer

Senior Fellow, VP

Director of Intel Labs

Technology Overview

Dr. Mario Paniccia

Intel Fellow

Director, Photonics Technology Lab

Q&A to Follow Presentation

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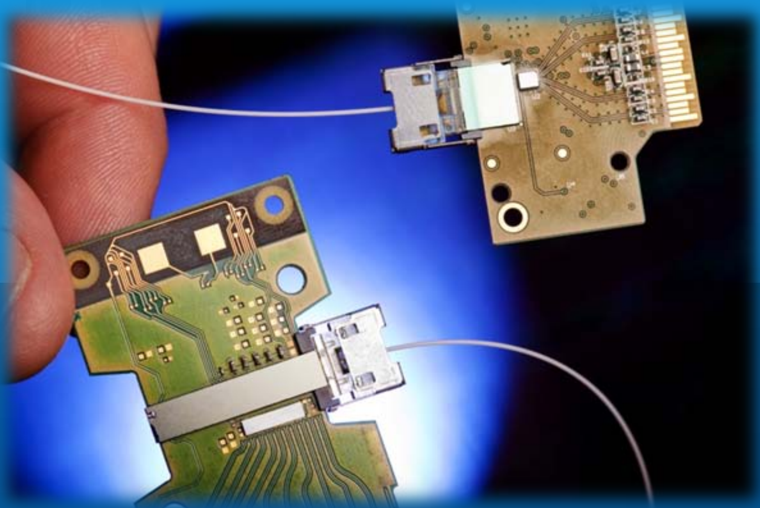
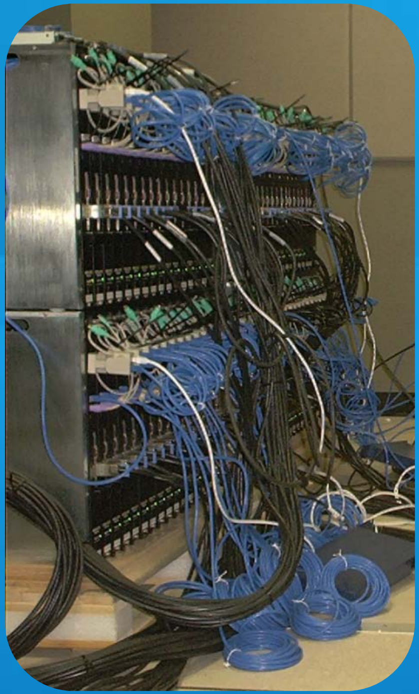
Today's news: 50Gbps Si Photonics Link

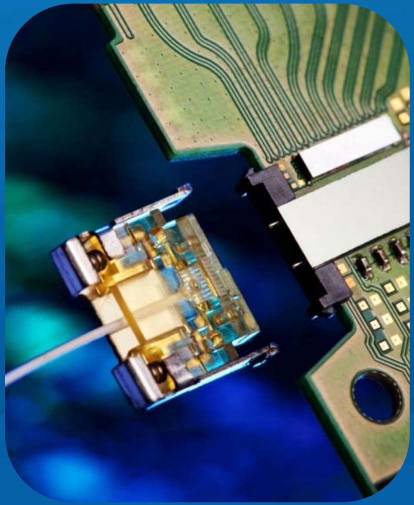
- **First silicon photonics data link with integrated lasers**
  - Research milestone using Hybrid Silicon Lasers
  - "Concept vehicle" runs at 50Gbps, scalable to 100Gbps, 400Gbps, …Tbps
- **Integrating our previous Si photonic building blocks**
  - Devices that emit, manipulate, combine, separate and detect light



- **Brings volume Si manufacturing to optical communications**

Could make optical communications affordable for any compute platform, revolutionize apps & architectures





Why Photonics?

Copper wires reaching physical limits

- ~10 Gbps or higher becoming challenging
- Distance/speed tradeoff shortens lengths

Alternative: Transmit data over optical fiber

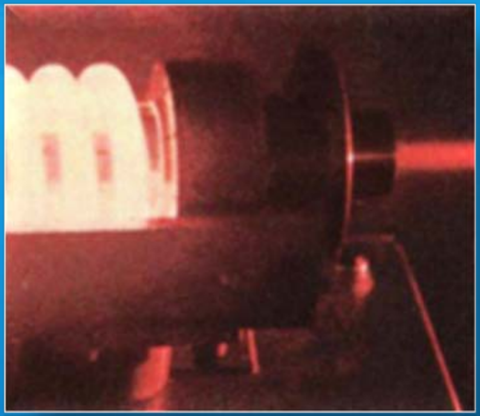
- Much further reach at any given speed
- Multiple signals can travel on one fiber
- Thin & light = easy cable management

Challenge: optical signaling technology is expensive

A Half Century of Innovation

Lasers

1960



First Laser
(Ted Maiman)

50 years

Today

Countless apps

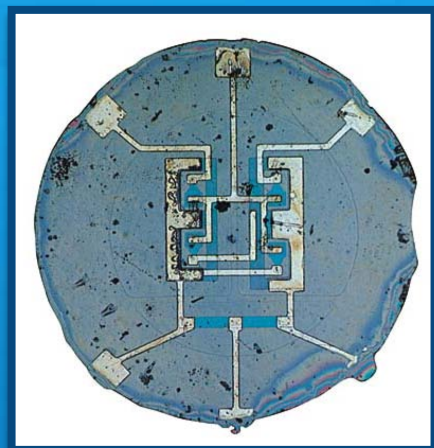
- Practical usages not known upon invention
- Laser has impacted industries from medicine to manufacturing to entertainment and more
- All long distance communications driven by lasers

Costs limits use of optical for everyday devices

A Half Century of Integration

Silicon

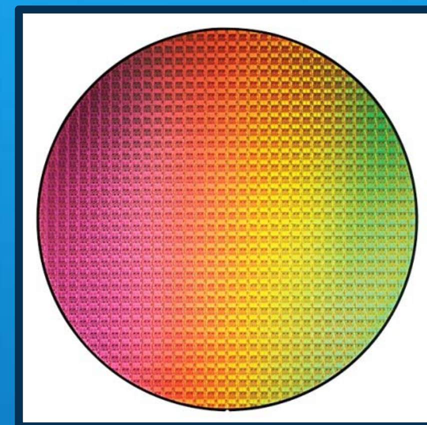
1959



First Silicon IC (Noyce and Kilby)

~50 years

Today



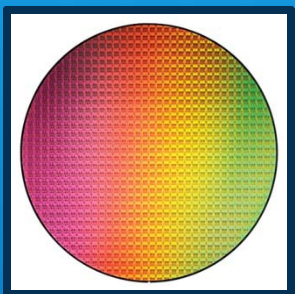
Billions of Transistors

- We have gone from 2 transistors to 2 billion
- This “Moore’s Law” scaling has led to transformative technologies
  - Mainframes -> Servers -> PCs -> Laptops -> Handhelds
  - Internet, e-commerce, social media
- **Silicon manufacturing has made this all possible**

intel

Bringing Si Manufacturing to Optical Comms

Si Manufacturing



High volume, low cost

Highly integrated

Scalable

+

Optical Communications

Very high bandwidth

Long distances

Immunity to electrical noise

=

OPTICAL ANYWHERE, INCREDIBLE POTENTIAL

Estimating the Exaflood, Discovery Institute, 1/08; *Amassing Digital Fortunes, a Digital Storage Study*, CEA, 3/08

A Wealth of Data to Move

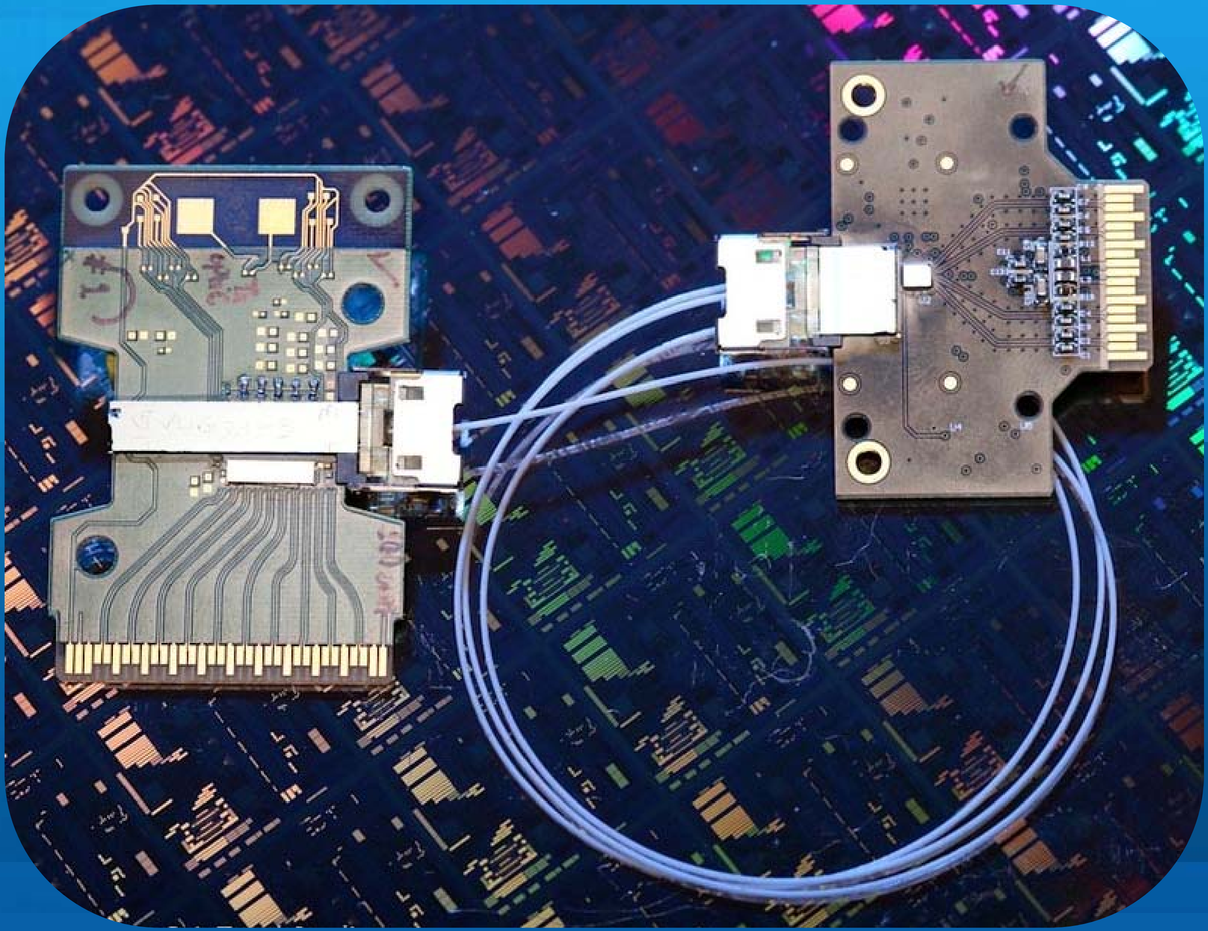
Personal Media	Business	Medical	Social Media	Science

Ave. Files on HD 54GB	Retail Customer DB 600 TB	Clinical Image DB ~1PB	HD video forecast 12 EB/yr	Physics (LHC) 300 EB/yr

More than 15B connected devices by 2015

Photonics can move more data farther & faster

50Gbps Si Photonics Link: Tech Overview

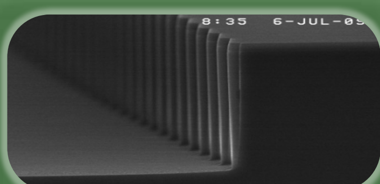


The Path to "Siliconizing" Photonics

Lasers

Hybrid Silicon Laser (Sept. '06)

Mux/Demux



Multiplexer and Demultiplexer

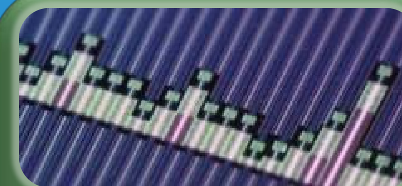
Data Encoders

Silicon Modulators
1GHz (Feb '04)
10 Gbps (Apr '05)
40 Gbps (July '07)

Basic Light Routing

Waveguides, couplers, etc...

Light detectors



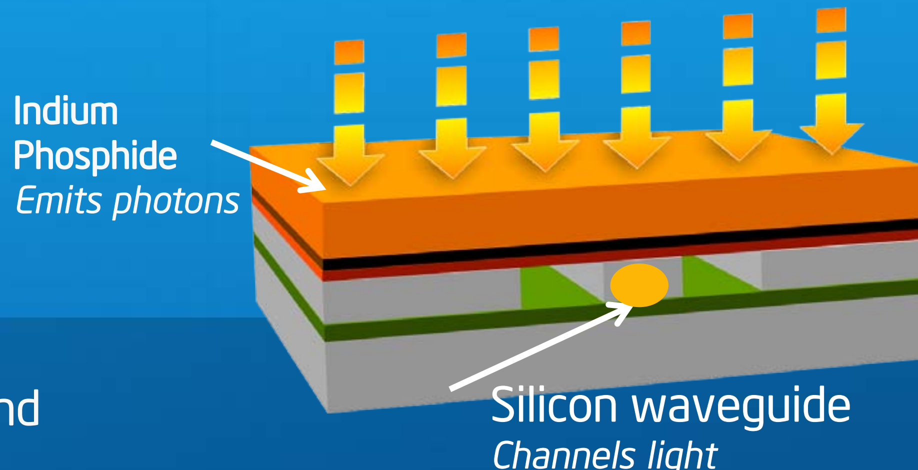
40 Gbps PIN Photodetectors (Aug. '07)

340 GHz Gain*BW Avalanche Photo-detector (Dec '08)

Numerous scientific breakthroughs in silicon photonic building blocks

Key Technology: Hybrid Silicon Laser

Research collaborations with Prof. John Bowers and team at UCSB paved way for Hybrid Silicon Laser breakthrough

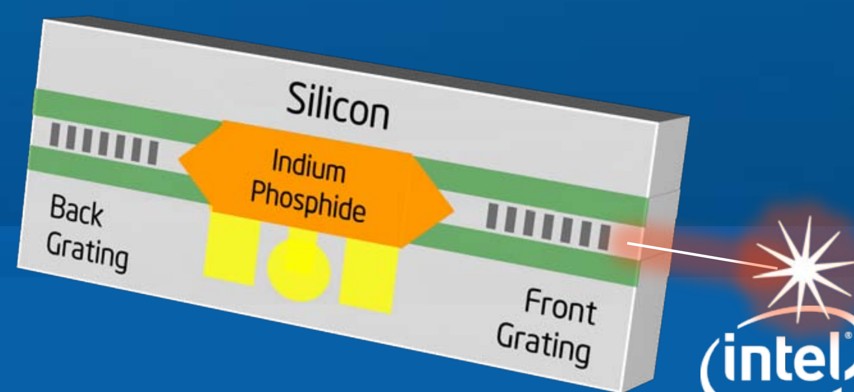


2006

-Intel & UCSB develop a unique process to fuse InP to Silicon
-Can create 1000s of lasers with one bond

2008

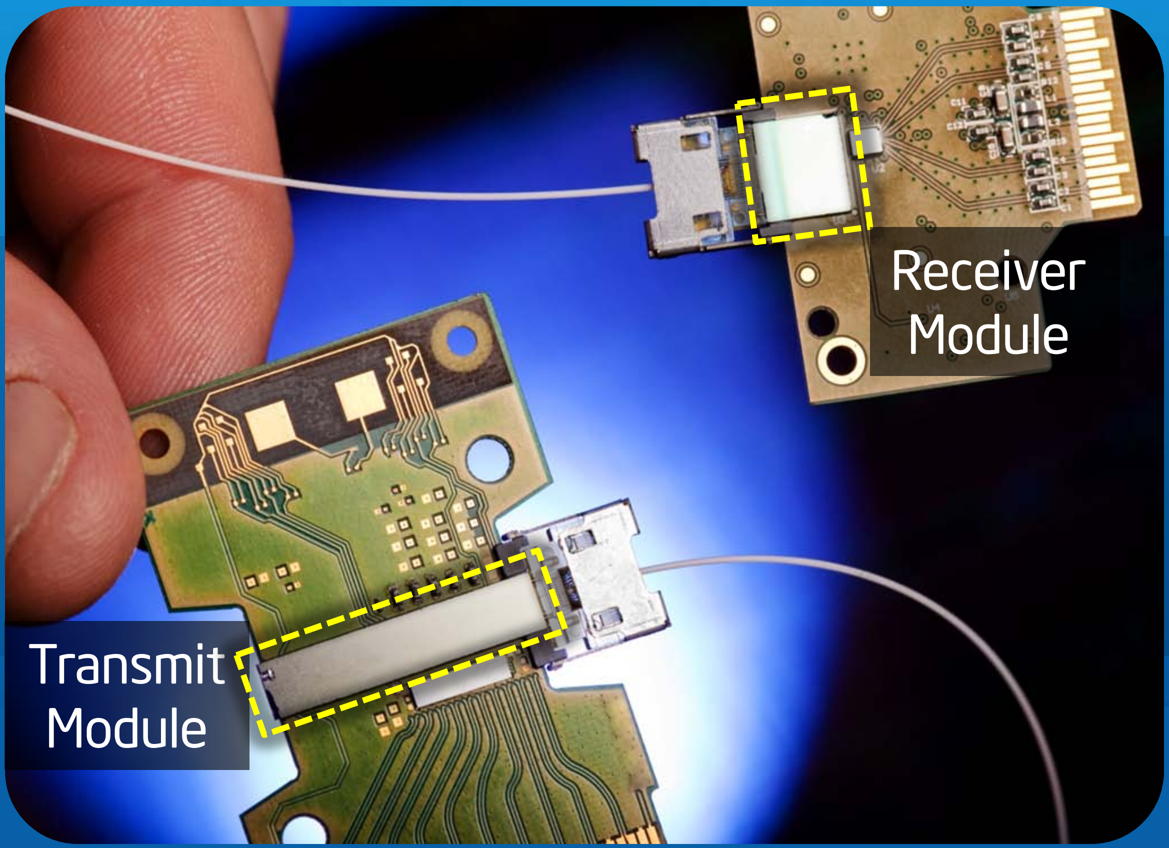
Added etched gratings into waveguides that act as “mirrors,” that are used to create different wavelengths of light



See backup slide 21 for more details on the Hybrid Silicon Laser

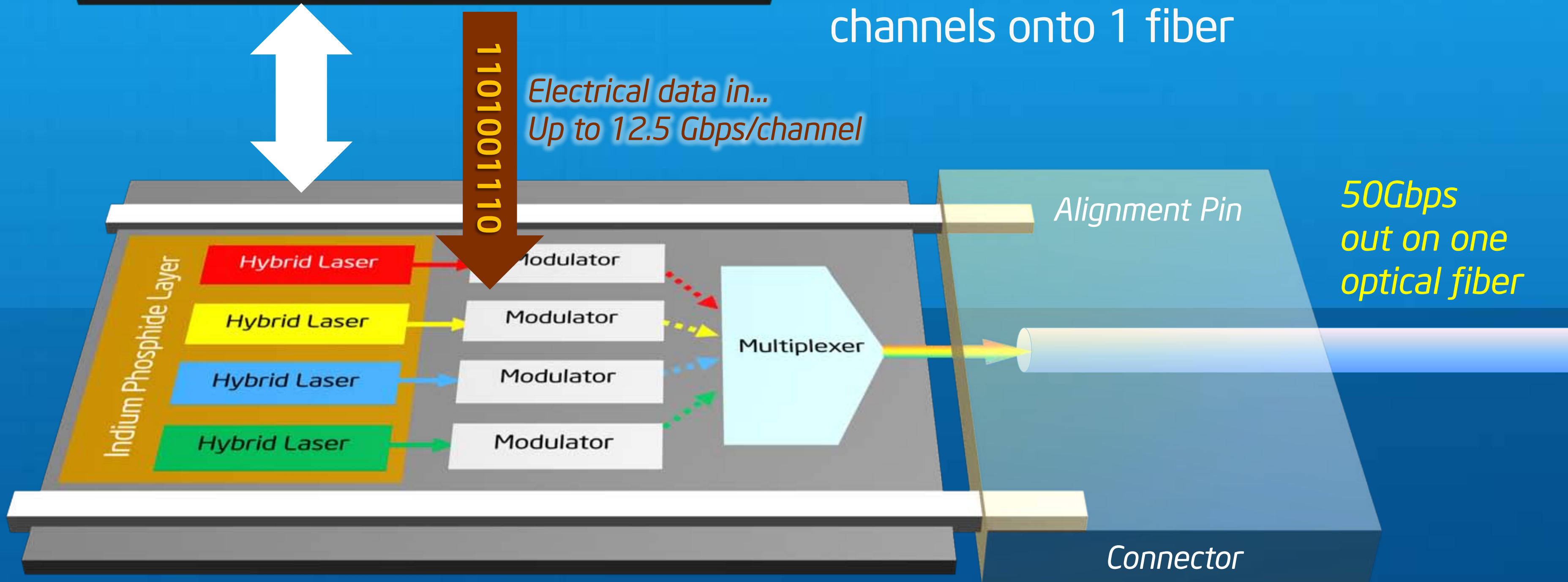
The 50Gbps Silicon Photonics Link

Transmitting and Receiving Light with Silicon



Integrated Transmitter Chip

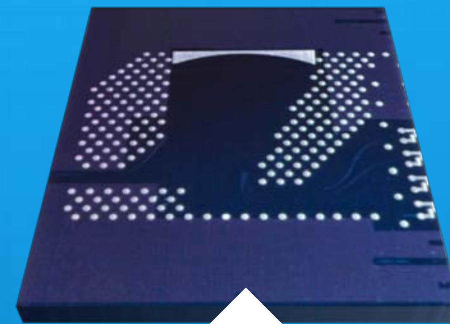
Integrates Hybrid Silicon Lasers With Modulators for data encoding and a Multiplexer to put 4 optical channels onto 1 fiber

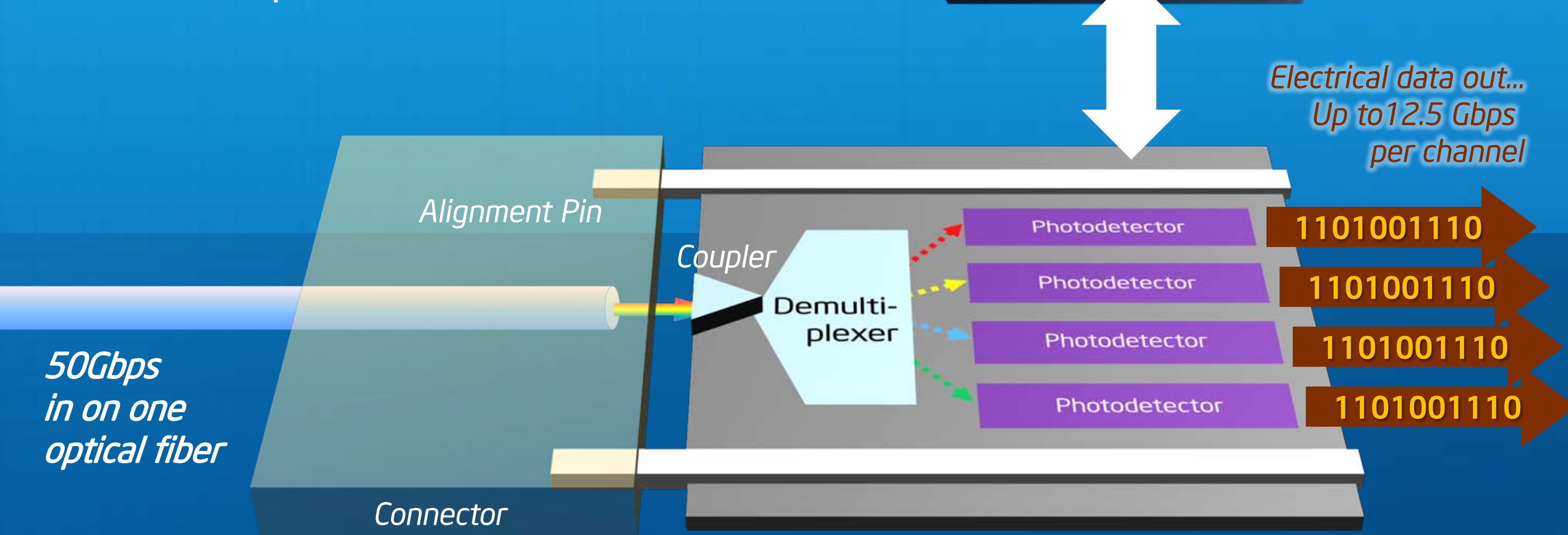


Parallel channels are key to scaling bandwidths at low costs

Integrated Receiver Chip

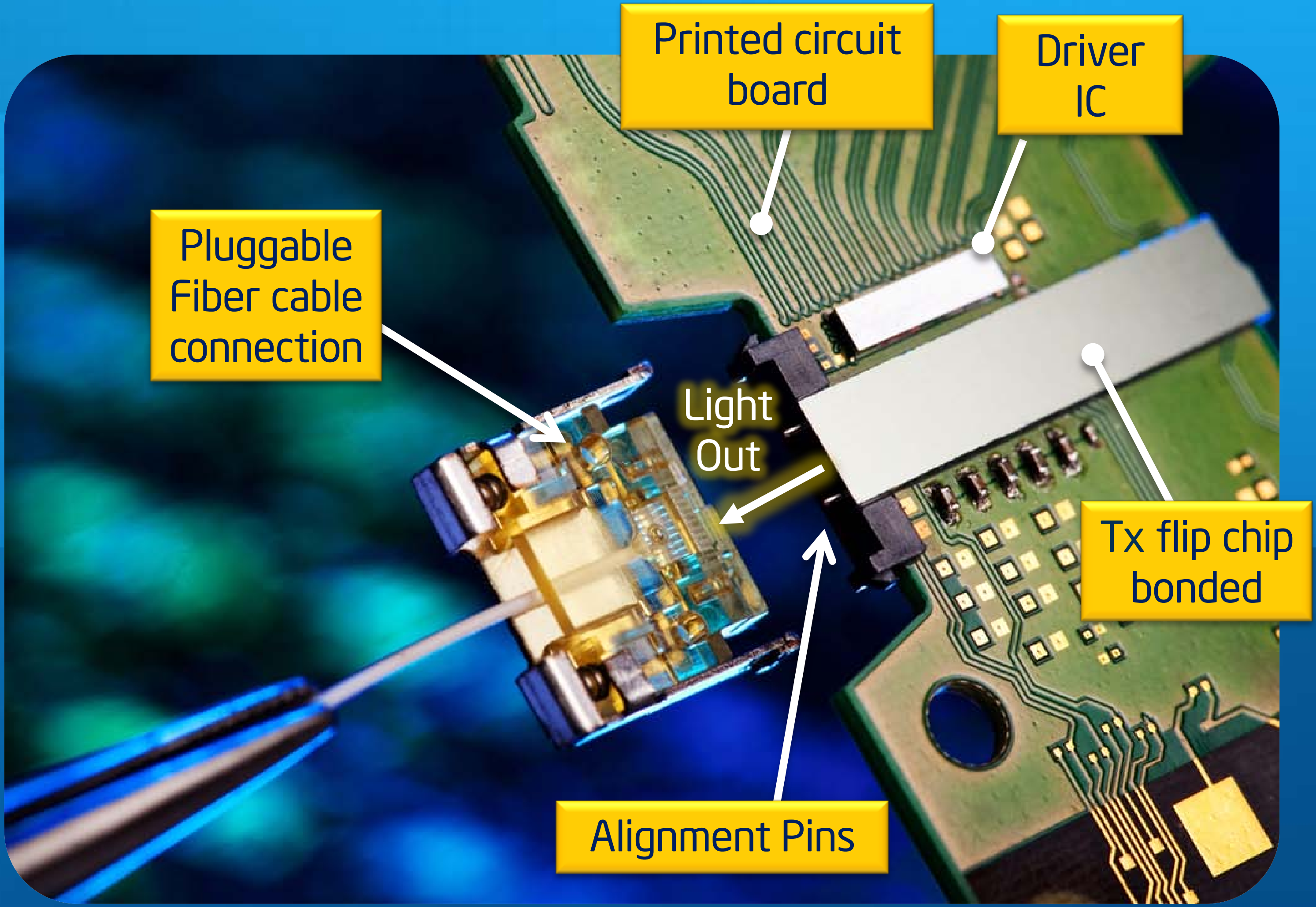
Integrates a coupler to receive incoming light with a demultiplexer to split optical signals and Ge-on-Si photodetectors to convert photons to electrons





Receives 4 optical channels at 12.5Gbps and converts to electrical data

Enabling for High Volume Assembly

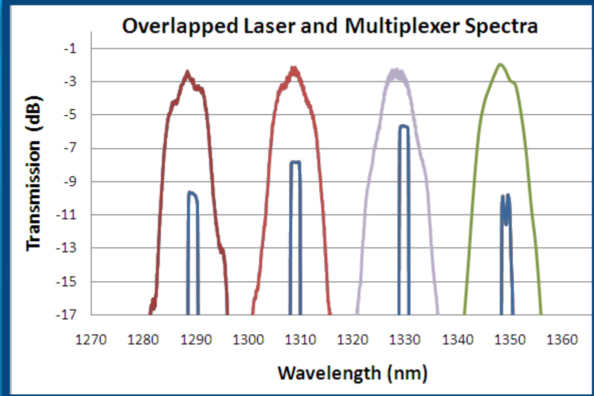


Built using "PC-board" assembly techniques and passive optical connections

Measured Data

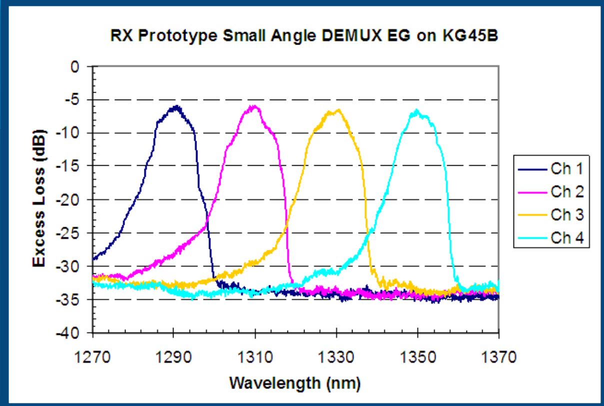
Transmit

4 hybrid Silicon Laser Outputs

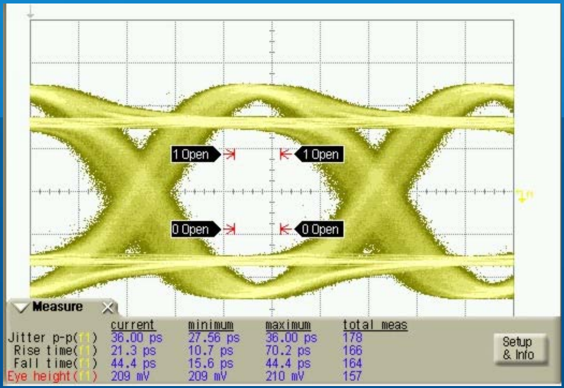


12.5Gbps data output per channel

Receive



De-Multiplexer separates wavelengths



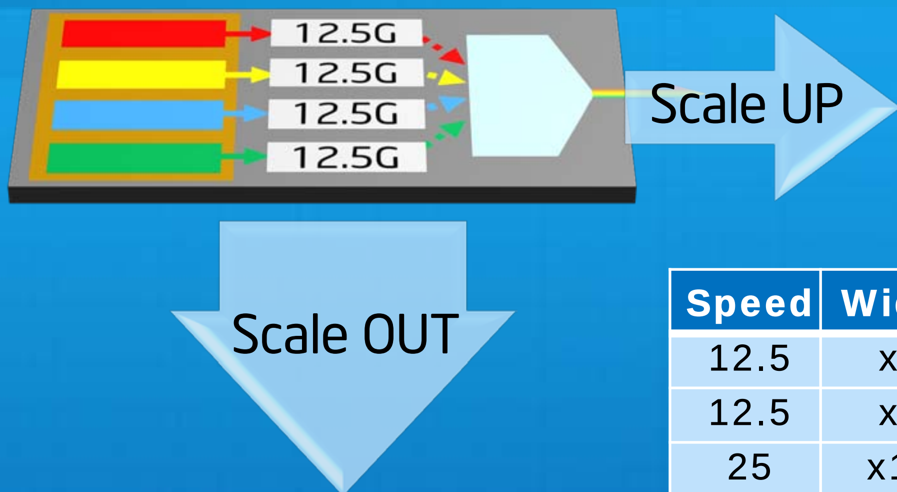
Electrical Output From Receiver

We ran link for more than a day with no errors (>1 Petabit)

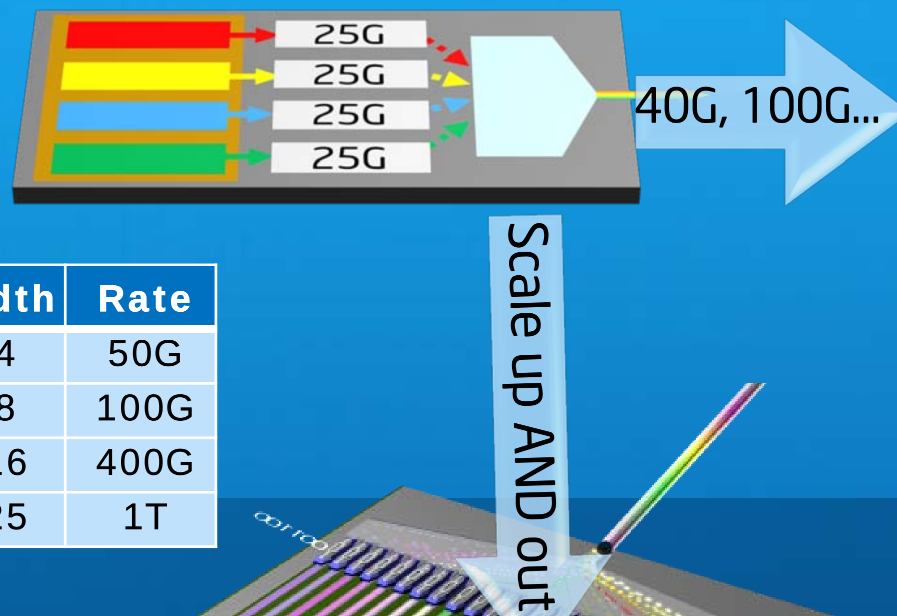
Translates to Bit-Error-Rate (BER) of < $3e^{-15}$

The Path to Tera-scale Data Rates

Today: 12.5 Gbps x 4 = 50Gbps

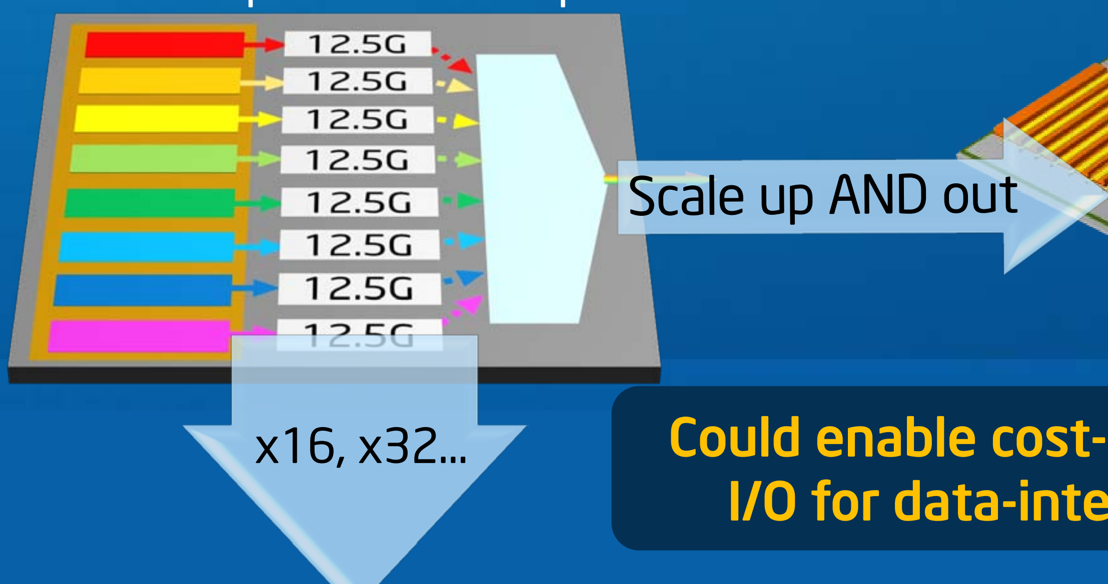


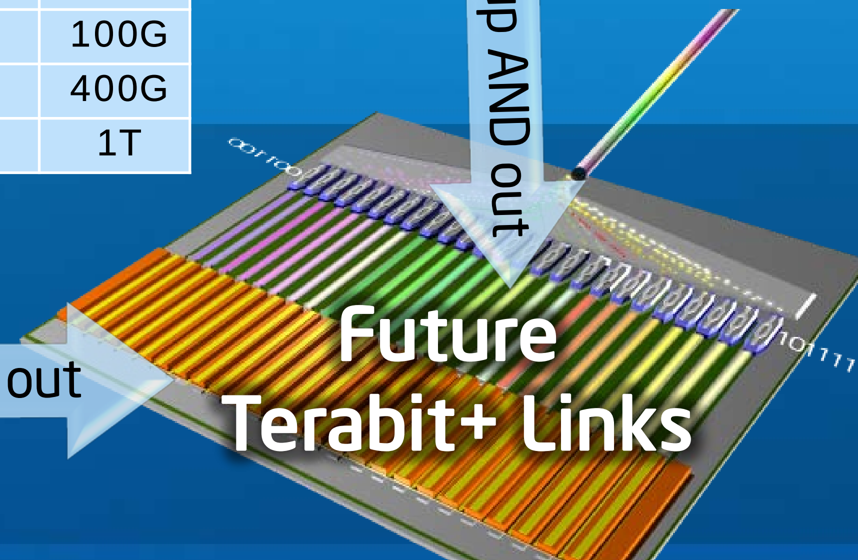
25 Gbps x 4 = 100Gbps



Speed	Width	Rate
12.5	x4	50G
12.5	x8	100G
25	x16	400G
40	x25	1T

12.5 Gbps x 8 = 100Gbps





Could enable cost-effective high speed I/O for data-intensive applications

What Could You Download in <ins><1 second</ins>?

At 50 Gigabit/s

- An HD movie from iTunes
- 100 hours of digital music
- 1000 High-res photos
- 45 million tweets!

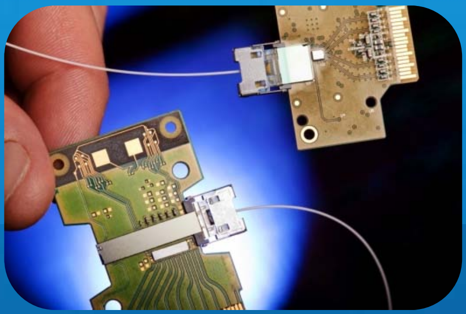
At 1 Terabit/s (Future)

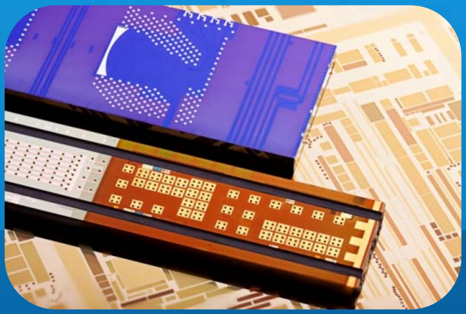
- 2-3 seasons of a TV drama in HD
- The contents of a laptop hard drive
- An entire music library:150+albums

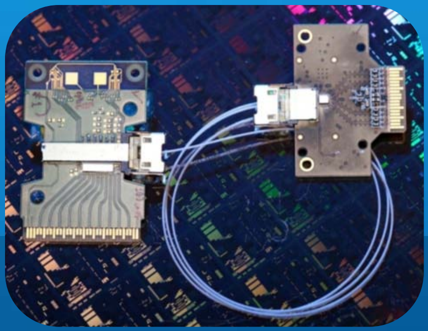
1 Tbps could download the entire printed collection of the Library of Congress in about 1½ minutes!

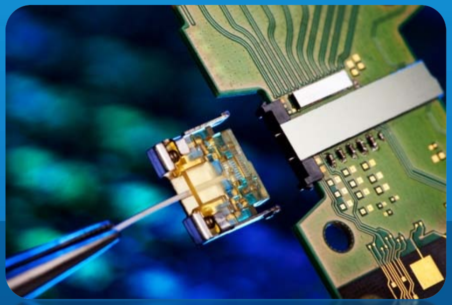
Recap: 50Gbps Silicon Photonics Link

- We've demonstrated the first complete data link using Silicon Photonics and integrated lasers, with exceptional performance
- Integrates our previous breakthrough Silicon Photonic building blocks









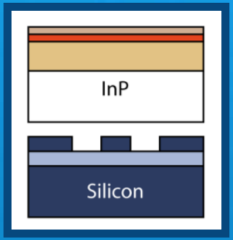
Going forward:

- Develop a high volume manufacturing process for Silicon Photonics
- Bring high bandwidth, low cost optical communications in and around future PCs, servers and consumer devices

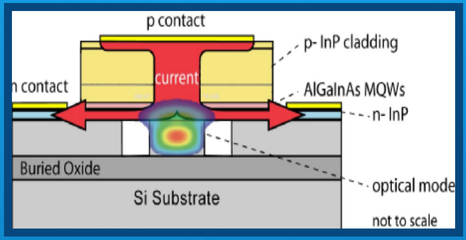

Thank You!
To learn more,
Visit www.intel.com/pressroom
and www.intel.com/go/sp

Hybrid Silicon Laser
(Developed with UCSB)

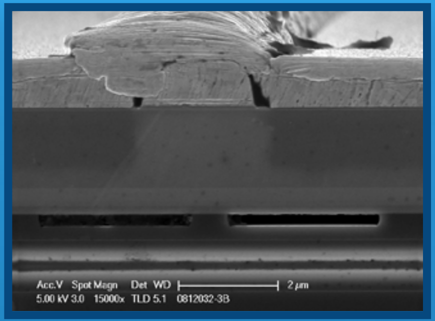
- Creating a Silicon-based laser by bonding a III-V material (Indium Phosphide) onto Silicon



InP bonded to Si

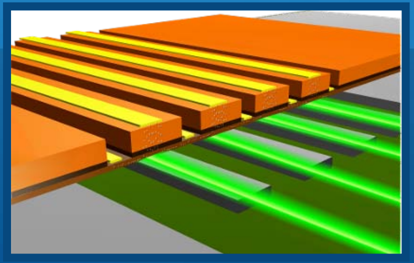


Cross Section of Hybrid Laser



SEM of Cross Section

- InP emits light when electrically stimulated
- Light bounces back and forth in silicon, and is amplified by the InP based material
- Mirrors are gratings etched into the silicon
  - Grating pitch defines the laser wavelength


One bond, no alignment needed

With ONE bond 1000's of lasers are aligned
Can produce different wavelengths by simple lithography

Press References

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