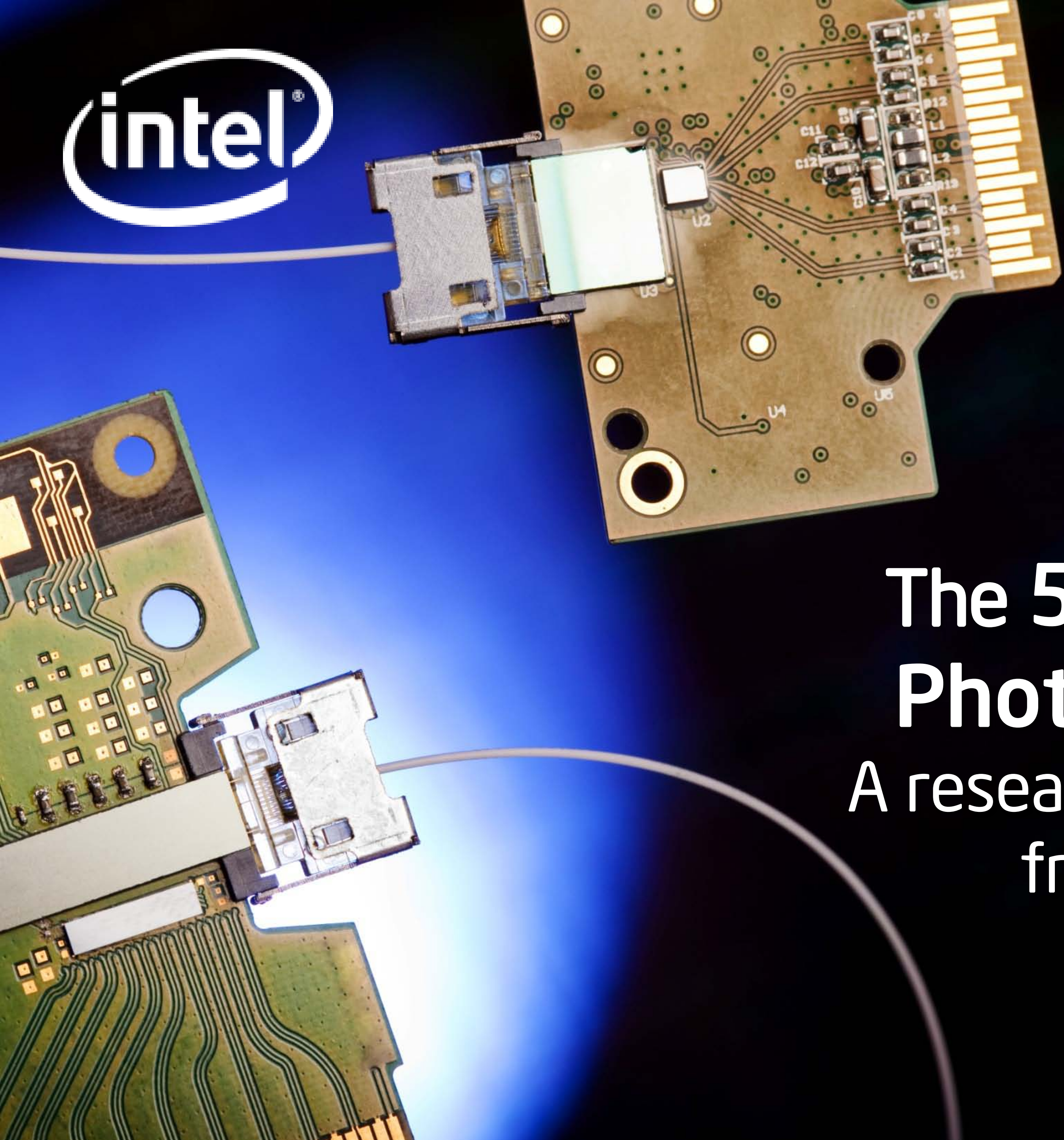
UNDER EMBARGO UNTIL 7/27/2010 10:30am PDT



The 50G Silicon Photonics Link

A research milestone from Intel Labs

Today's Agenda

- Today's news
- Impact and applications
- Technical overview
- Questions and answers

Speaker:

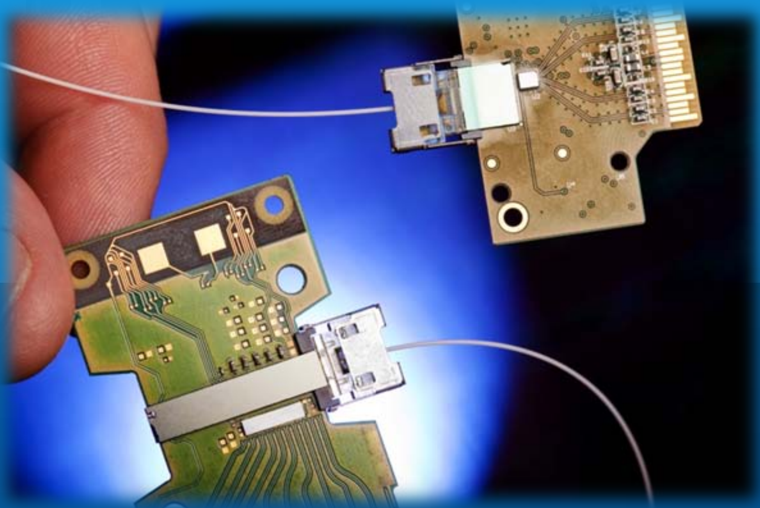
Dr. Mario Paniccia

Intel Fellow

Director, Photonics Technology Lab

Today's news: 50G Silicon Photonics Link

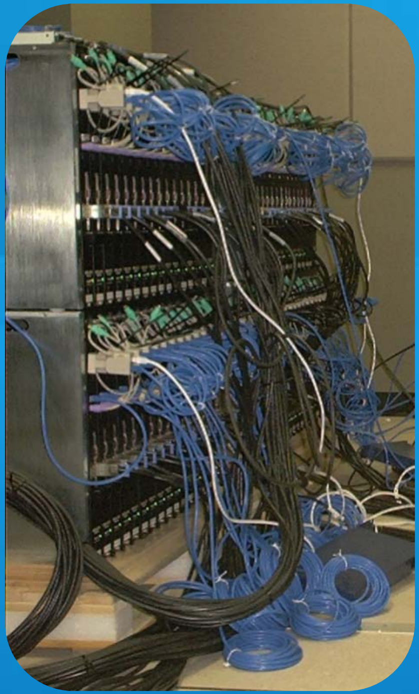
- **First Silicon Photonics data link with integrated lasers**
  – Research milestone using Hybrid Silicon Lasers
  – "Concept vehicle" runs at 50Gbps, scalable to 100G, 400G, …Terabit/s….



- **Integrates our previous breakthrough building blocks**
  – Devices to emit, manipulate, combine, separate and detect light

- **Brings silicon manufacturing to optical communications**

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



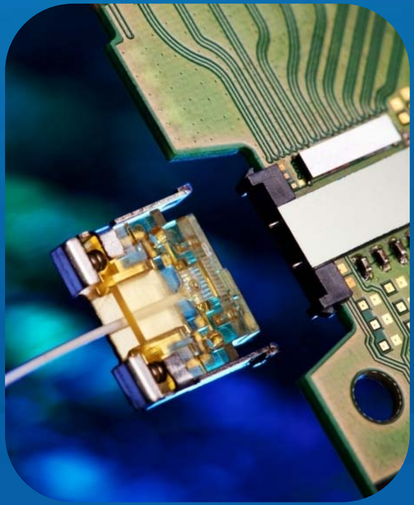
Why Photonics?

Copper wires reaching physical limits

- ~10 Gbps or higher becoming challenging
- Distance/speed tradeoff costing more in energy

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

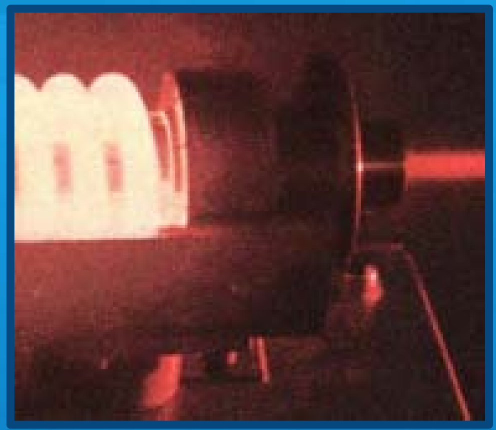


Challenge: Optical technology is expensive

A Half Century of Innovation

<u>1960</u> | <u>Today</u>

Lasers



First Laser
(Ted Maiman)

50 years

Countless apps

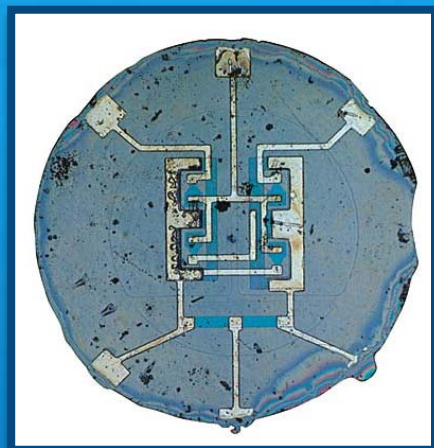
- Practical usages not known upon invention
- Laser has impacted industries from medicine to manufacturing to entertainment and more
- All long distance communications driven by lasers

Costs limits use of optical for everyday devices

A Half Century of Integration

Silicon

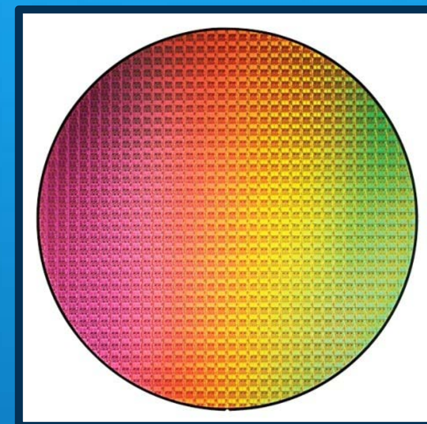
1959



First Silicon IC (Noyce and Kilby)

~50 years

Today

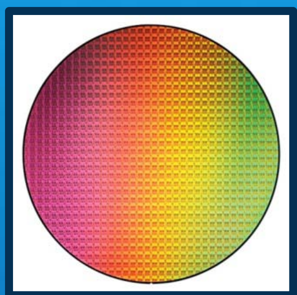


Billions of Transistors

- 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**

Bringing Si Manufacturing to the Laser

Si Manufacturing



High volume, low cost

Highly integrated

Scalable

+

Lasers

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

Kiosks

Medical Imaging

Network Appliances

Digital Signage

Test & Measurement

Security Surveillance

In-Vehicle Infotainment

More than 15B connected devices by 2015

Photonics can move more data farther & faster

Example: Advanced Video Technology

3D Displays

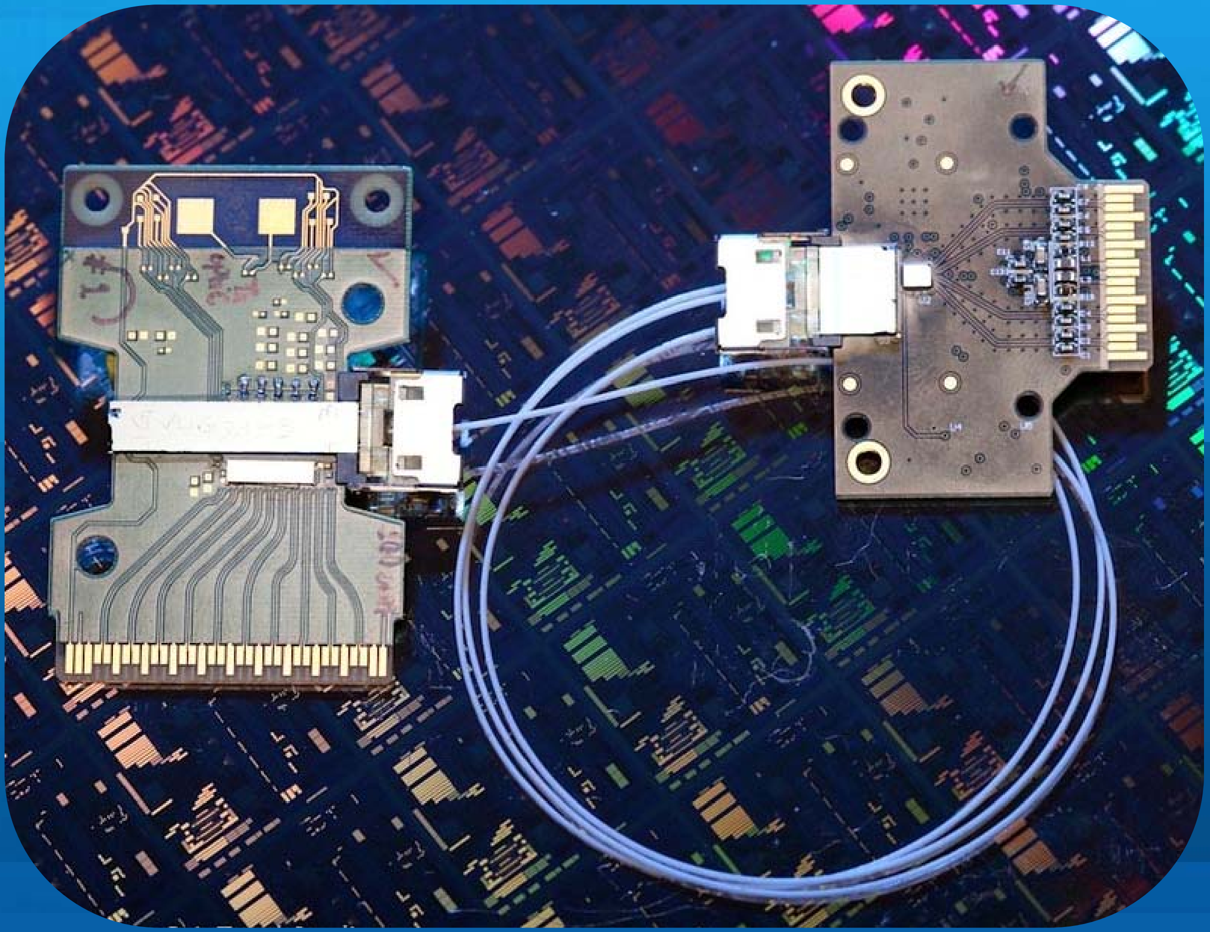
High Dynamic Range

	24Hz		48Hz		60Hz		120Hz (3D)	
HDR Increase (color depth)	24	48	24	48	24	48	24	48
Today: Full HD 1080p	1.19 Gbps	2.39 Gbps	2.39 Gbps	4.78 Gbps	2.99 Gbps	5.97 Gbps	5.97 Gbps	11.94 Gbps
Tomorrow : Quad HD 2160p	4.78 Gbps	9.56 Gbps	9.56 Gbps	19.11 Gbps	11.94 Gbps	23.89 Gbps	23.89 Gbps	47.78 Gbps

Future: Ultra High Definition (4320p, 30bpp, 60Hz) needs **60 Gbps!**

Photonic links could facilitate better TV experiences

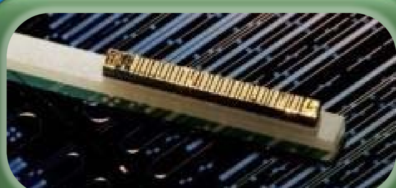
50G Si Photonics Link: Tech Overview



The Path to "Siliconizing" Photonics

Lasers

1st Continuous Wave Silicon Raman Laser (Feb. '05)



Hybrid Silicon Laser (Sept. '06)

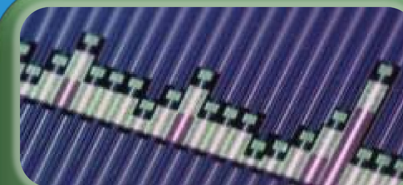
Data Encoders

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

Basic Light Routing

Waveguides, multiplexers, demultiplexers, couplers...

Light detectors



40 Gbps PIN Photodetectors (Aug. '07)

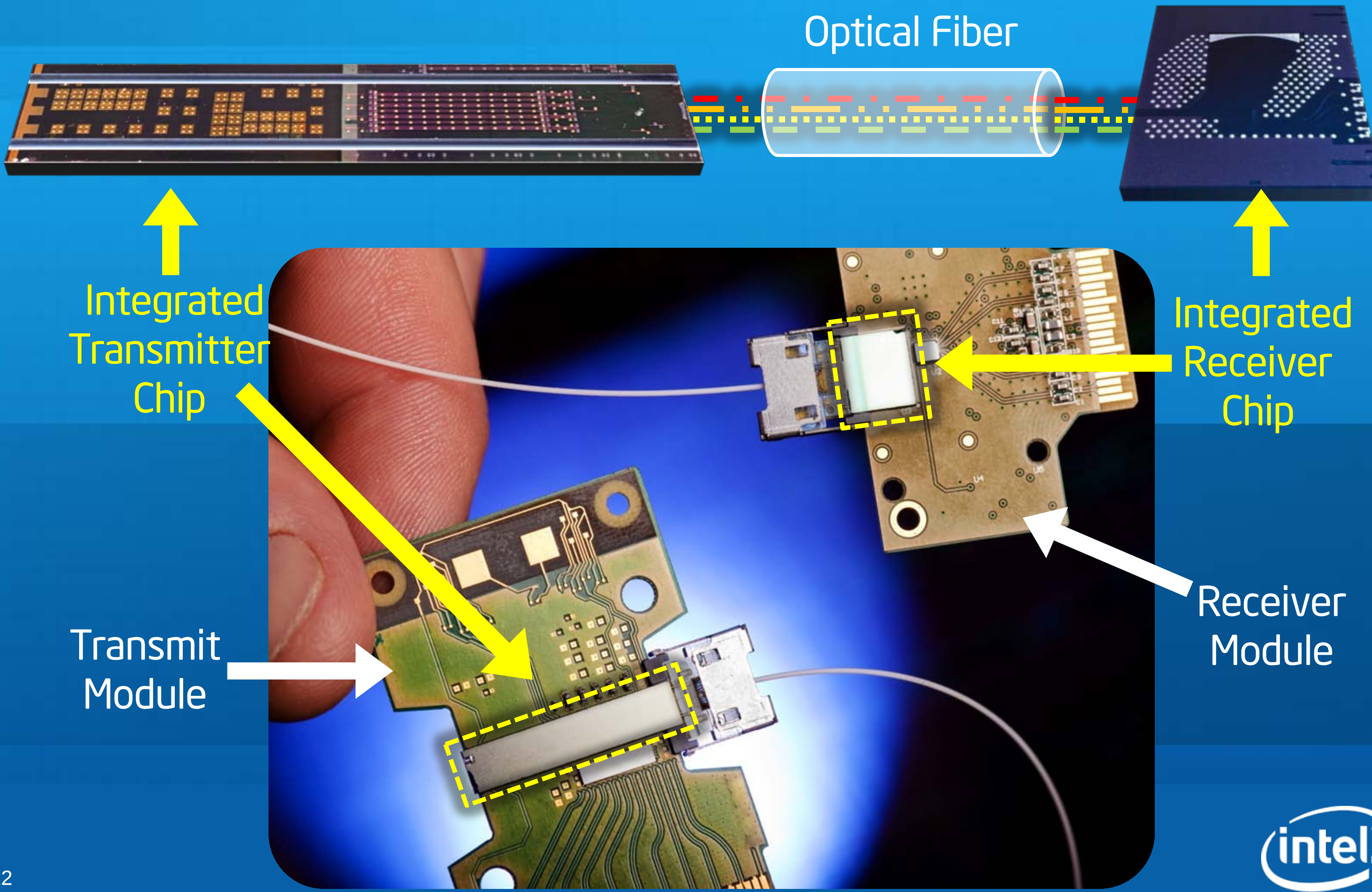
340 GHz Gain*BW Avalanche Photo-detector (Dec '08)

Numerous scientific breakthroughs in silicon photonic building blocks

intel

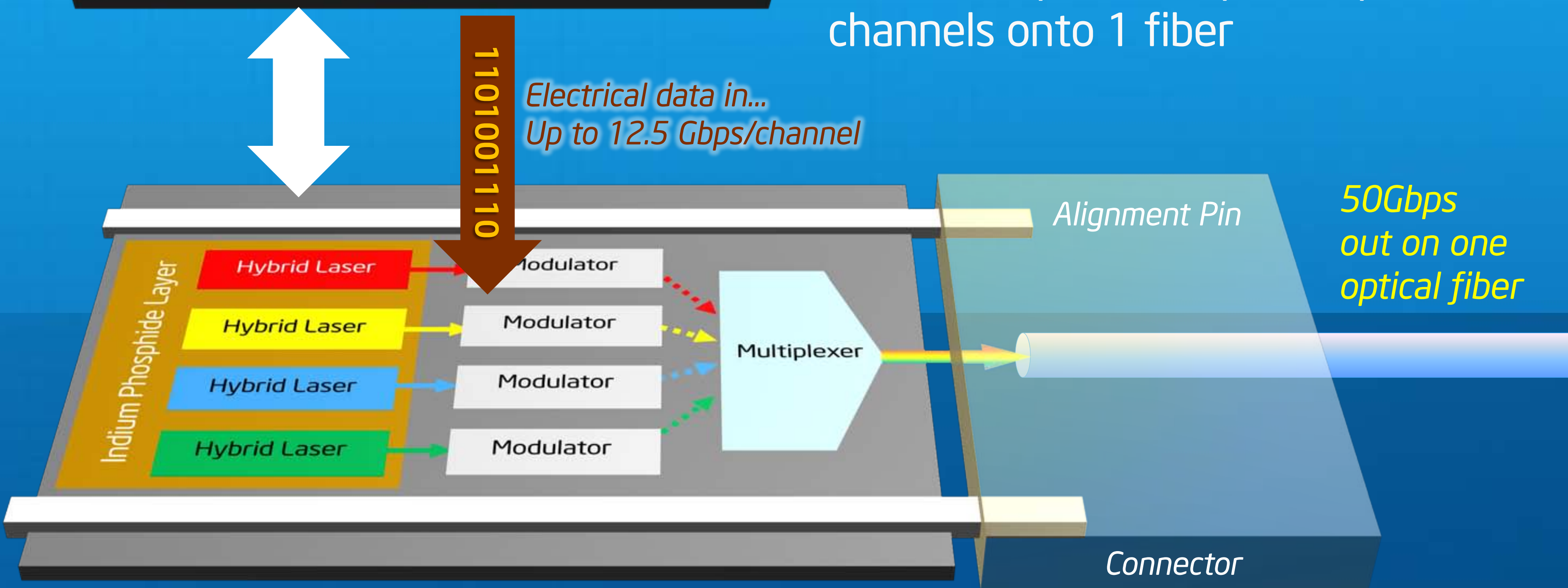
The 50G Silicon Photonics Link

Transmitting and Receiving Light with Silicon



Integrated Transmitter Chip

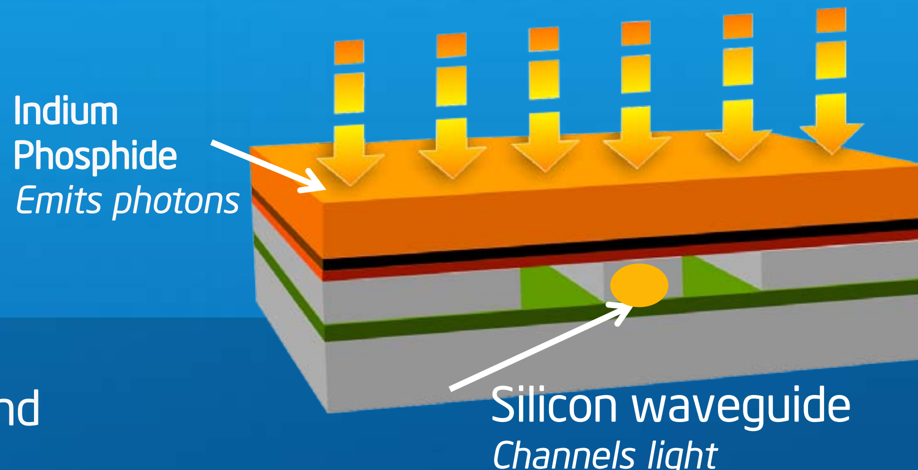
Integrates Hybrid Silicon Lasers With Modulators for data encoding and a Multiplexer to put 4 optical channels onto 1 fiber



Parallel channels are key to scaling bandwidths at low costs

Key Technology: Hybrid Silicon Laser

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

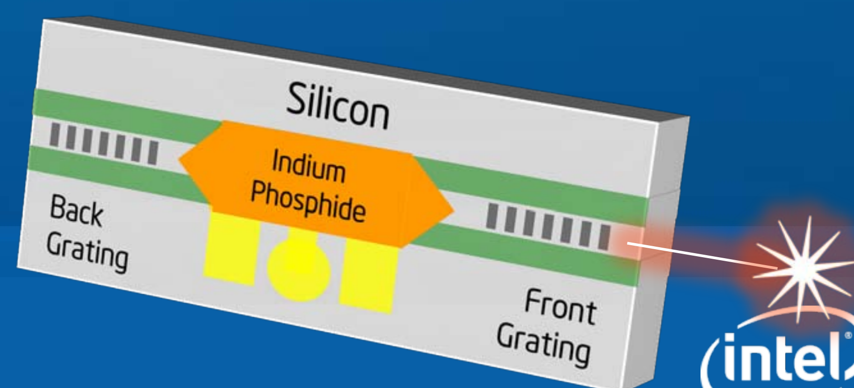


2006

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

2008

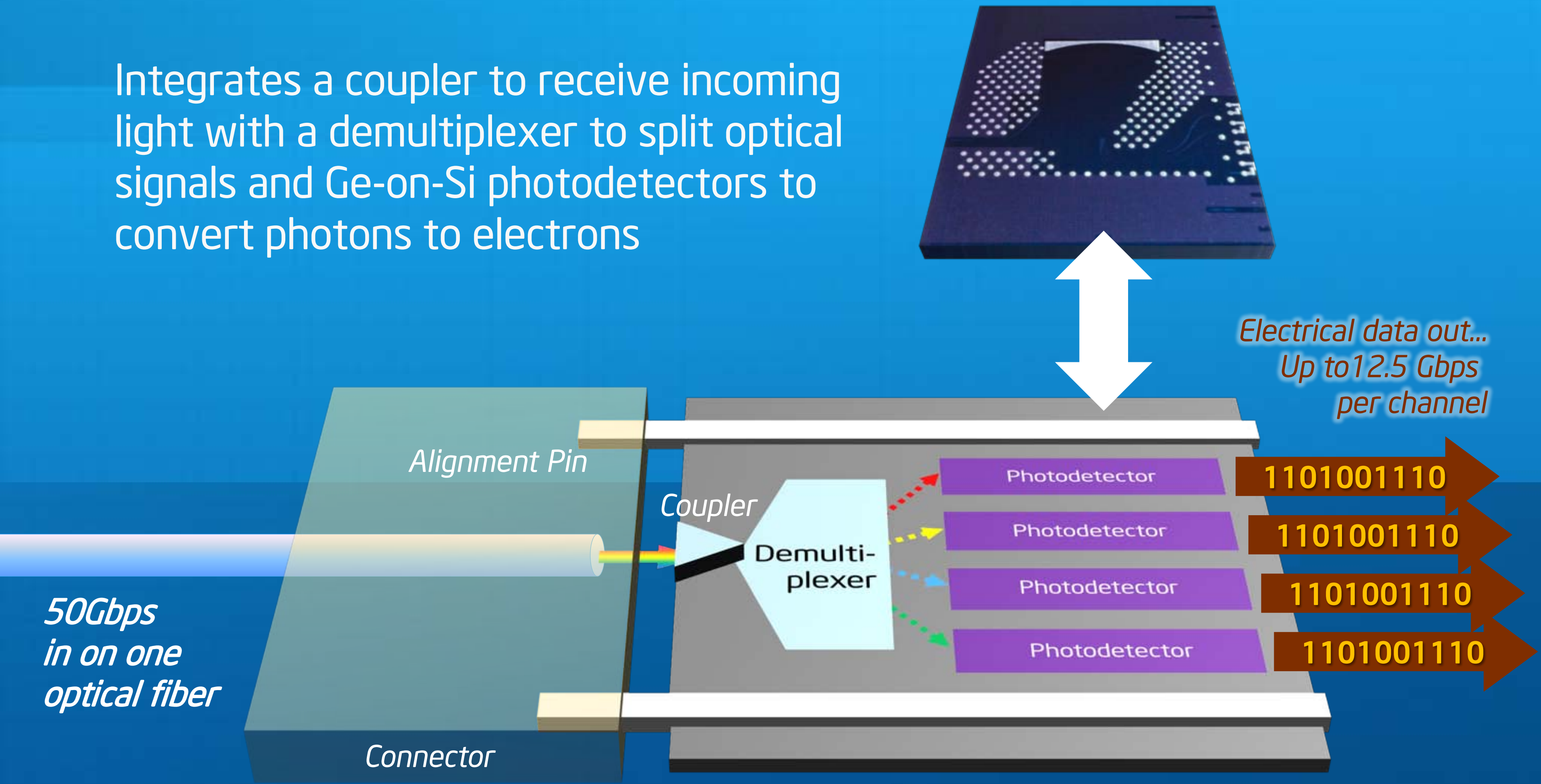
Added etched gratings into waveguides that act as "mirrors," that are used to create different wavelengths of light



See backup slide 24 for more details on the Hybrid Silicon Laser

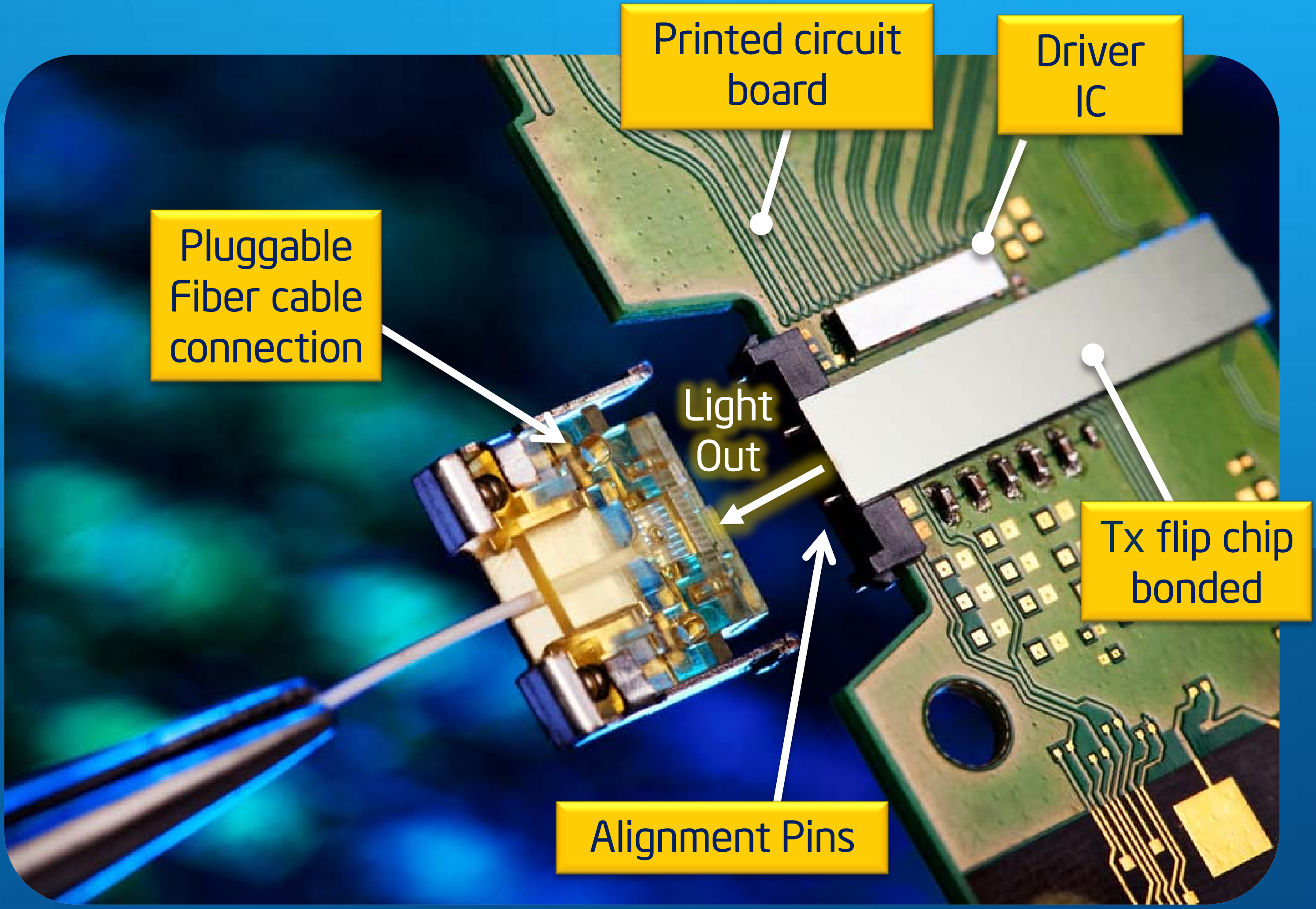
Integrated Receiver Chip

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



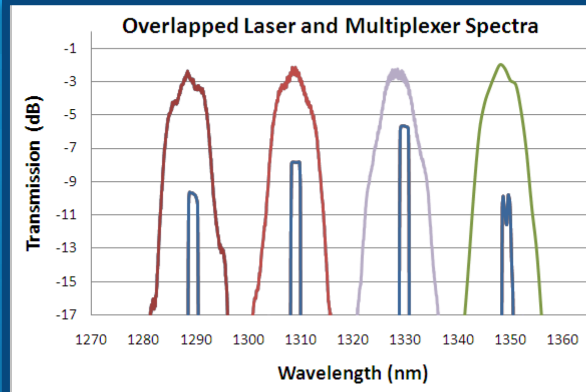
Built using "PC-board" assembly techniques and passive optical connections

All data collected by Intel

Measured Data

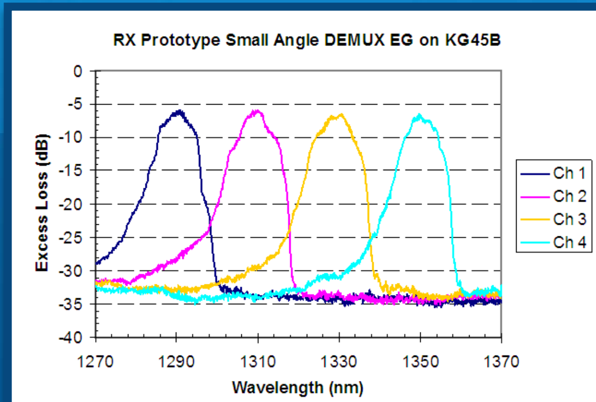
Transmit

4 hybrid Silicon Laser Outputs

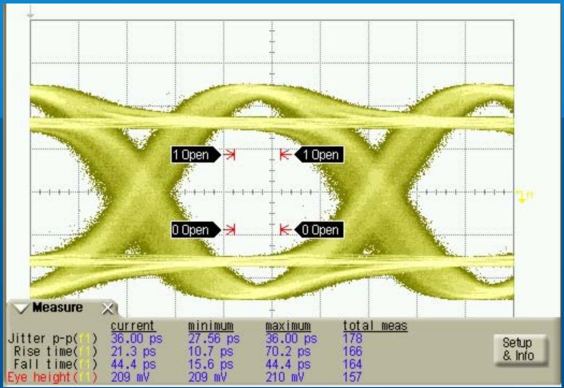


12.5Gbps data output per channel

Receive



De-Multiplexer separates wavelengths



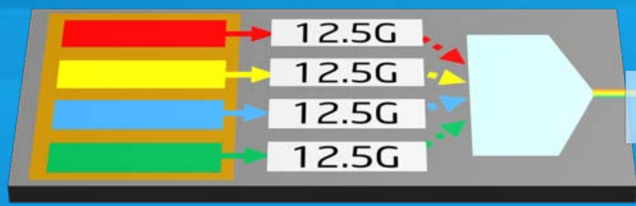
Electrical Output From Receiver

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



Scale UP

25 Gbps x 4 = 100Gbps

40G, 100G…

Scale OUT

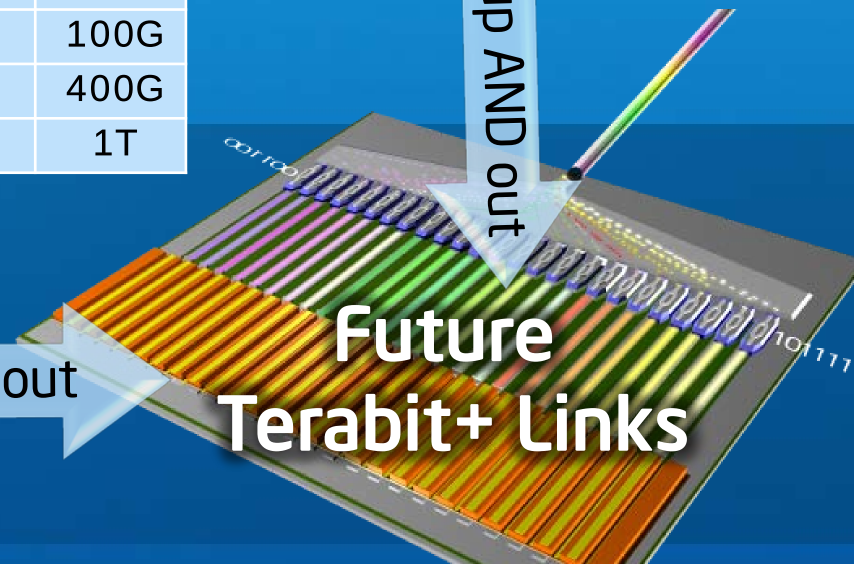
Speed	Width	Rate
12.5	x4	50G
12.5	x8	100G
25	x16	400G
40	x25	1T

Scale up AND out

12.5 Gbps x 8 = 100Gbps

x16, x32…

Scale up AND out



Future Terabit+ Links

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

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

At 50 Gigabit/s

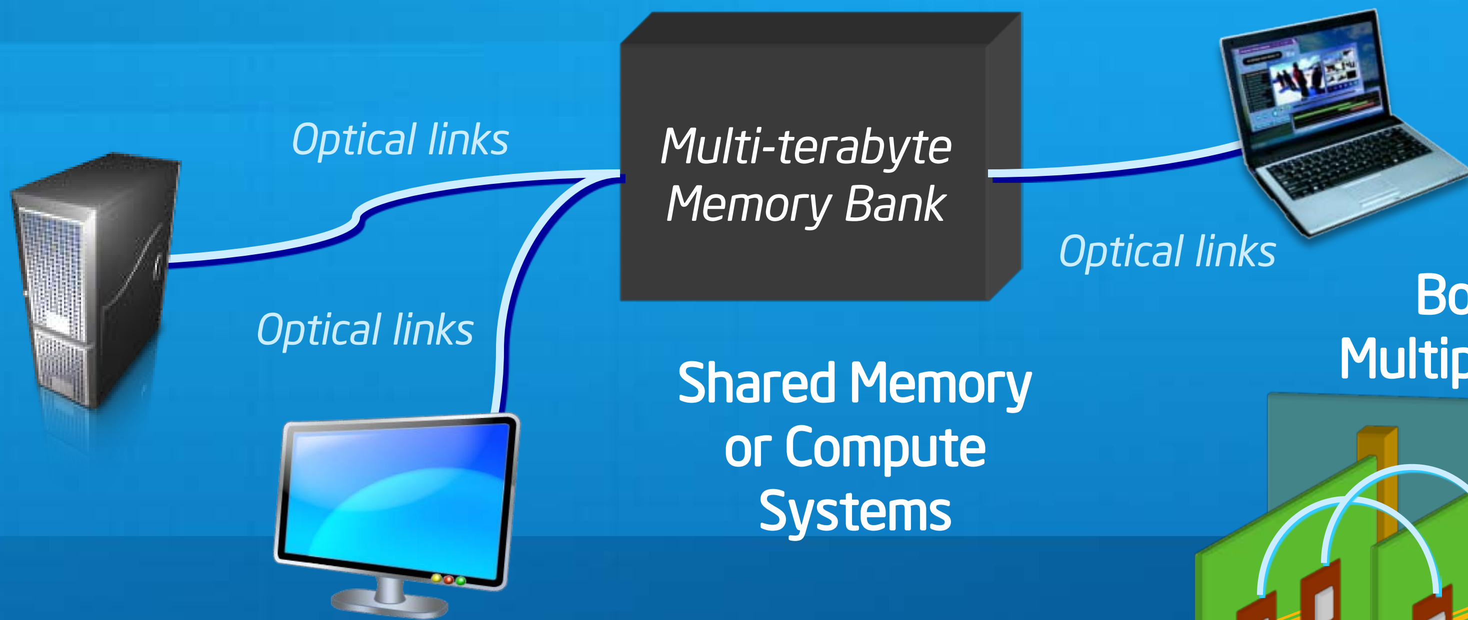
- An HD movie from iTunes
- 100 hours of digital music
- 1000 High-res photos
- 45 million tweets!

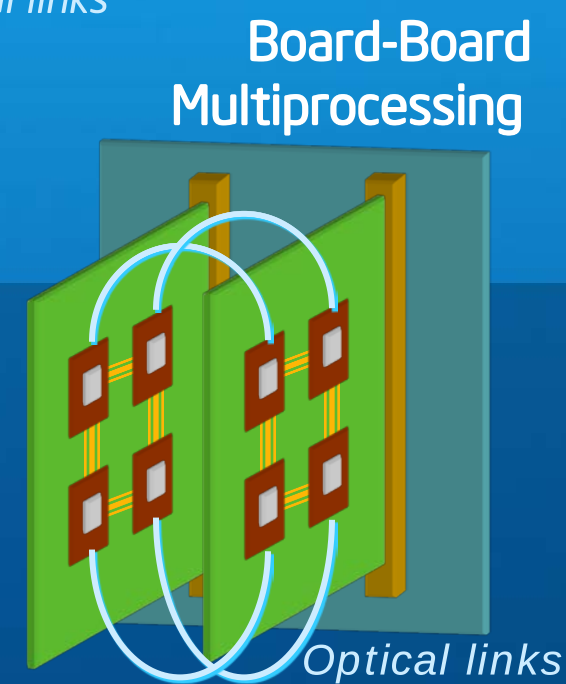
At 1 Terabit/s (Future)

- 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!

Eliminating Distance Constraints





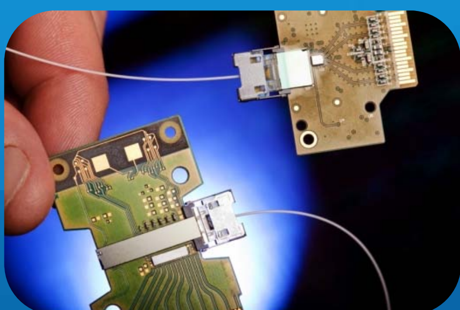
New opportunities to:

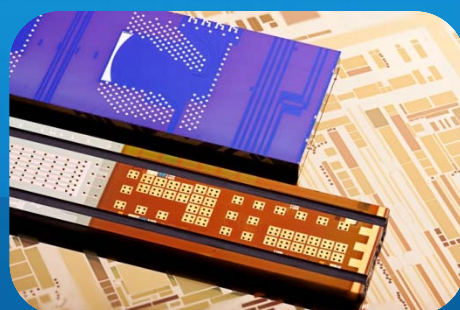
- Increase performance
- Reduce system costs
- Reduce thermal density

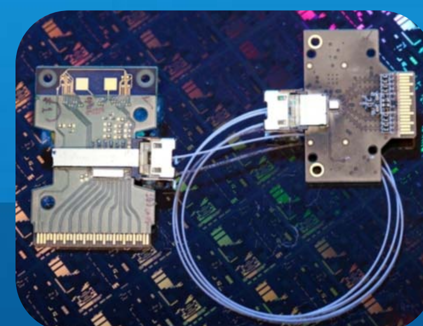
Could revolutionize architectures for datacenters and cloud computing

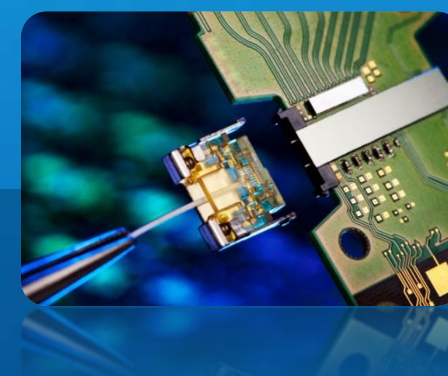
Recap: 50G Silicon Photonics Link

- First Silicon Photonics data link with integrated laser
- Brings silicon manufacturing scalability to the Laser
- Integrates our previous breakthrough building blocks









Going forward:

- Scale “up” and “out” towards Terabit/s bandwidth
- Optimize our integration process and packaging
- Enable data-intensive apps for future Intel platforms

Thank You!

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

Press References

Industry Analysts:

- Martin Reynolds, Gartner VP
  +1-510-657-7067, Martin.reynolds@gartner.com
- Jim McGregor, InStat Principal Analyst
  +1-480-609-4554, jmcgregor@in-stat.com

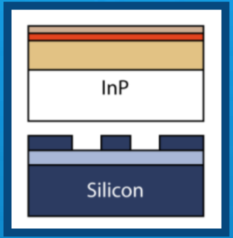
Optical Technology Experts:

- Prof John Bowers, University of California at Santa Barbara
  Hybrid Silicon Laser expert and research collaborator
  +1-805-886-2357, bowers@ece.ucsb.edu
- Prof Graham Reed, University of Surrey, UK
  Early silicon photonics pioneer and modulator expert
  +44 7833 626597, G.Reed@surrey.ac.uk (traveling in Pacific time zone)
- Prof Alan Willner, University of Southern California,
  Laser and high speed systems expert
  +1-213-272- 6942 willner@email.usc.edu (traveling in Eastern time zone)

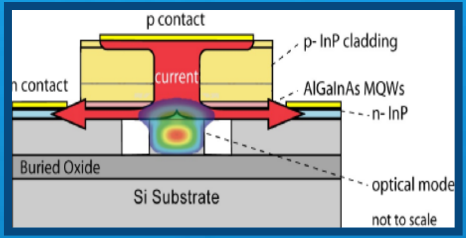
Hybrid Silicon Laser

(Developed with UCSB)

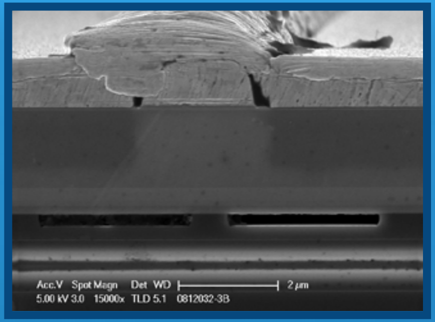
- Creating a Silicon-based laser by bonding a III-V material (Indium Phosphide) onto Silicon



InP bonded to Si

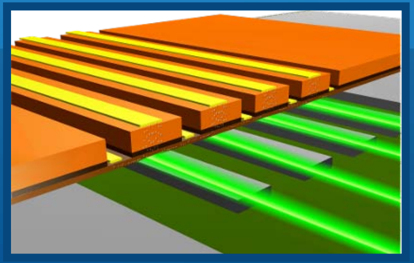


Cross Section of Hybrid Laser



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