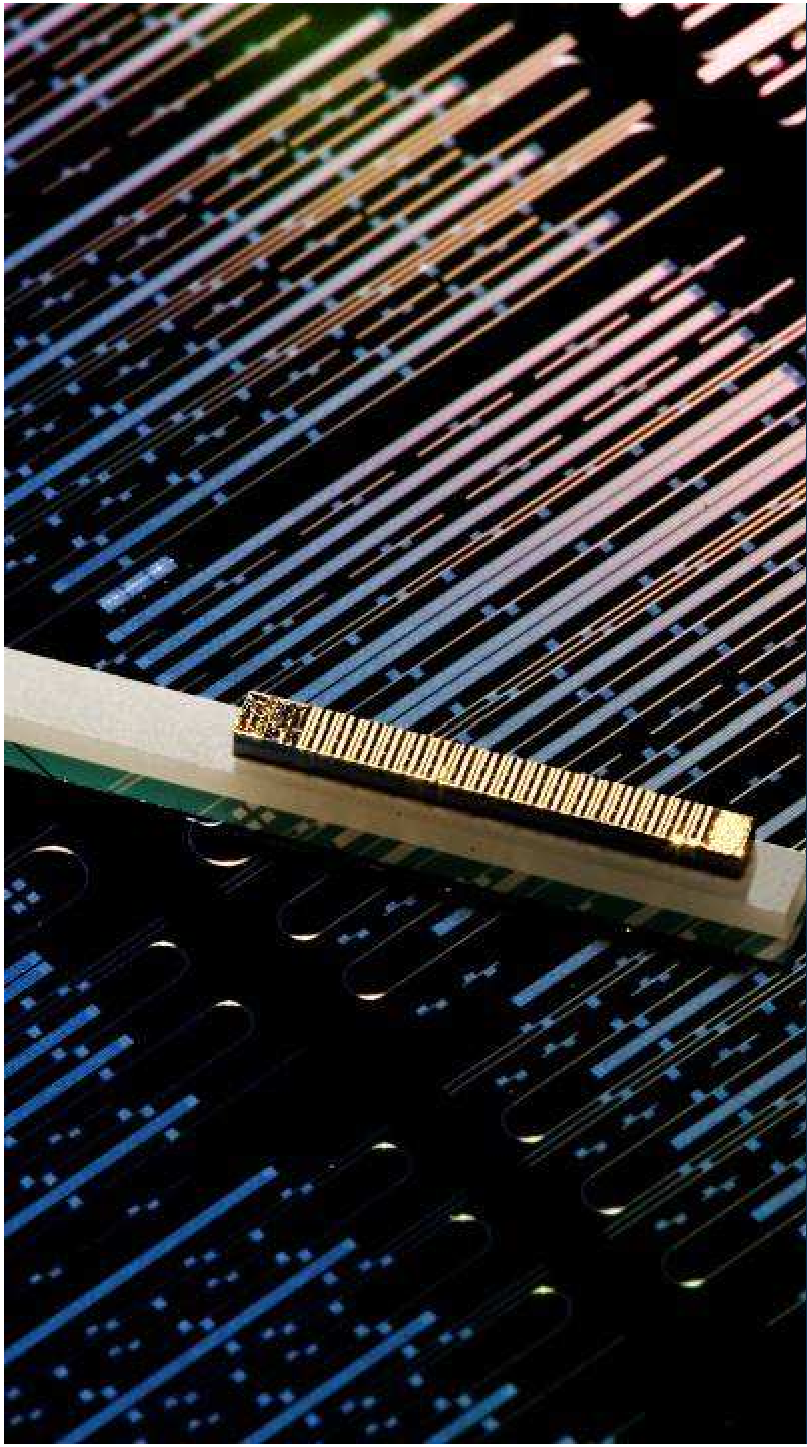

irst Electrically Pumped Hybrid Silicon Laser

Sept 18th 2006

The information in this presentation is under embargo until 9/18/06– 10:00 AM PST

Agenda

Dr. Mario Paniccia

Director, Photonics Technology Lab

Dr. John Bowers

Professor, UC Santa Barbara

- **What We are Announcing**
- **Silicon Photonics Overview**
- **Lasers & Light Emission with Silicon Photonics**
- **Joint Collaboration – Hybrid Silicon Laser**
- **Hybrid Silicon Laser Test Results**
- **Summary**

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What We are Announcing

- Research Breakthrough: 1st Electrically pumped Hybrid Silicon Laser
  - A joint collaboration between UCSB and Intel Corporation
  - Combines the light emitting capabilities of Indium phosphide with the high volume, low cost capabilities of silicon
  - Addresses one of the last major hurdle to silicon photonic chips
- Vision:
  - Build chips containing 10 to 100s of Hybrid Silicon Lasers
  - Built using high-volume, low cost manufacturing processes
  - Enables terabit optical links
- Background
  - Silicon is a poor light emitter while Indium phosphide based materials are great light emitters
  - However, Indium phosphide lasers are expensive to manufacture
  - Novel design combined with a manufacturing process where a unique “glass glue” was used to bond the two materials together

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The Photonic Dilemma

- Fiber can carry much more bandwidth than copper

- However, it is much more expensive…..

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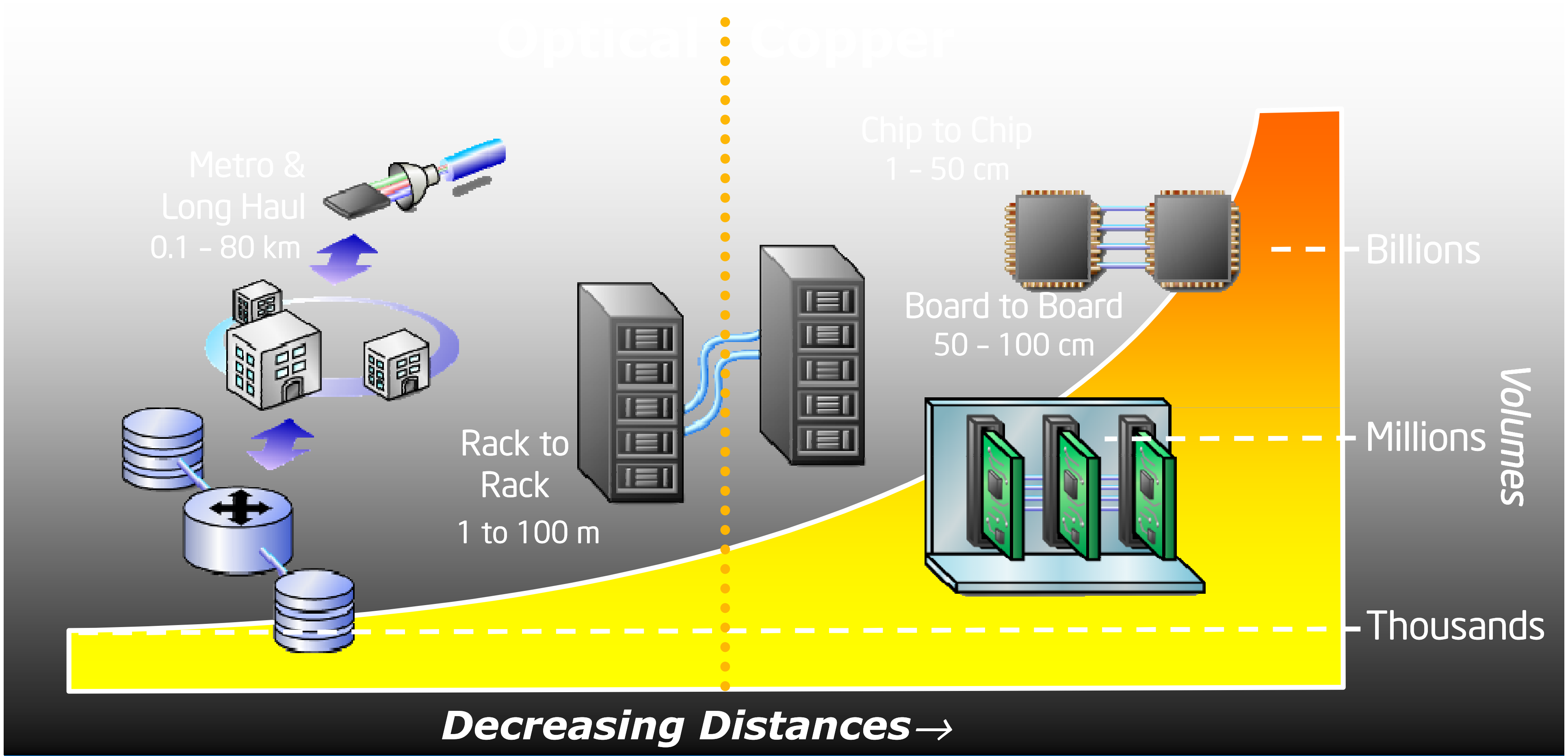
Today's High Speed Interconnects



Goal: Drive optical to high volumes and low costs

Photonics: ***The technology of emission, transmission, control and detection of light (photons) aka fiber-optics & opto-electronics***

Today: ***Most photonic devices made with exotic materials, expensive processing, complex packaging***

Silicon Photonics Vision: ***Research effort to develop photonic devices using silicon as base material and do this using standard, high volume silicon manufacturing techniques in existing fabs***

Benefit: Bring volume economics to optical communications

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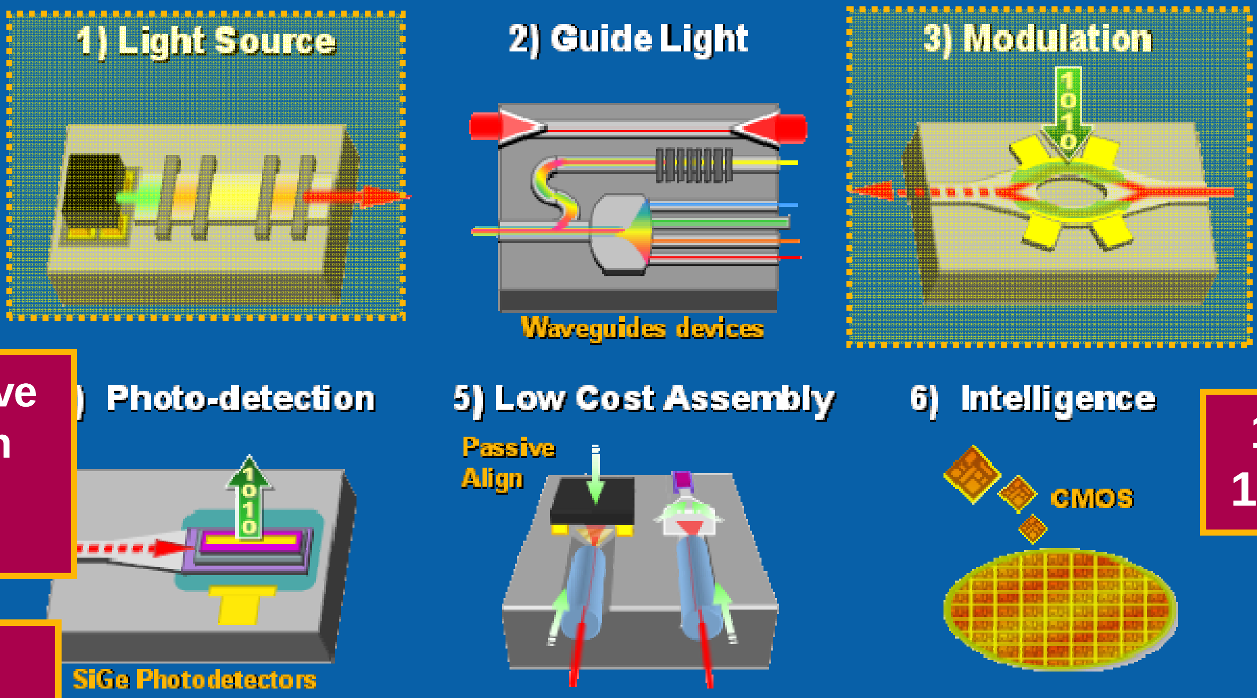
Intel’s Silicon Photonics Research



Continuous Wave Silicon Raman Laser
(Feb ‘05)

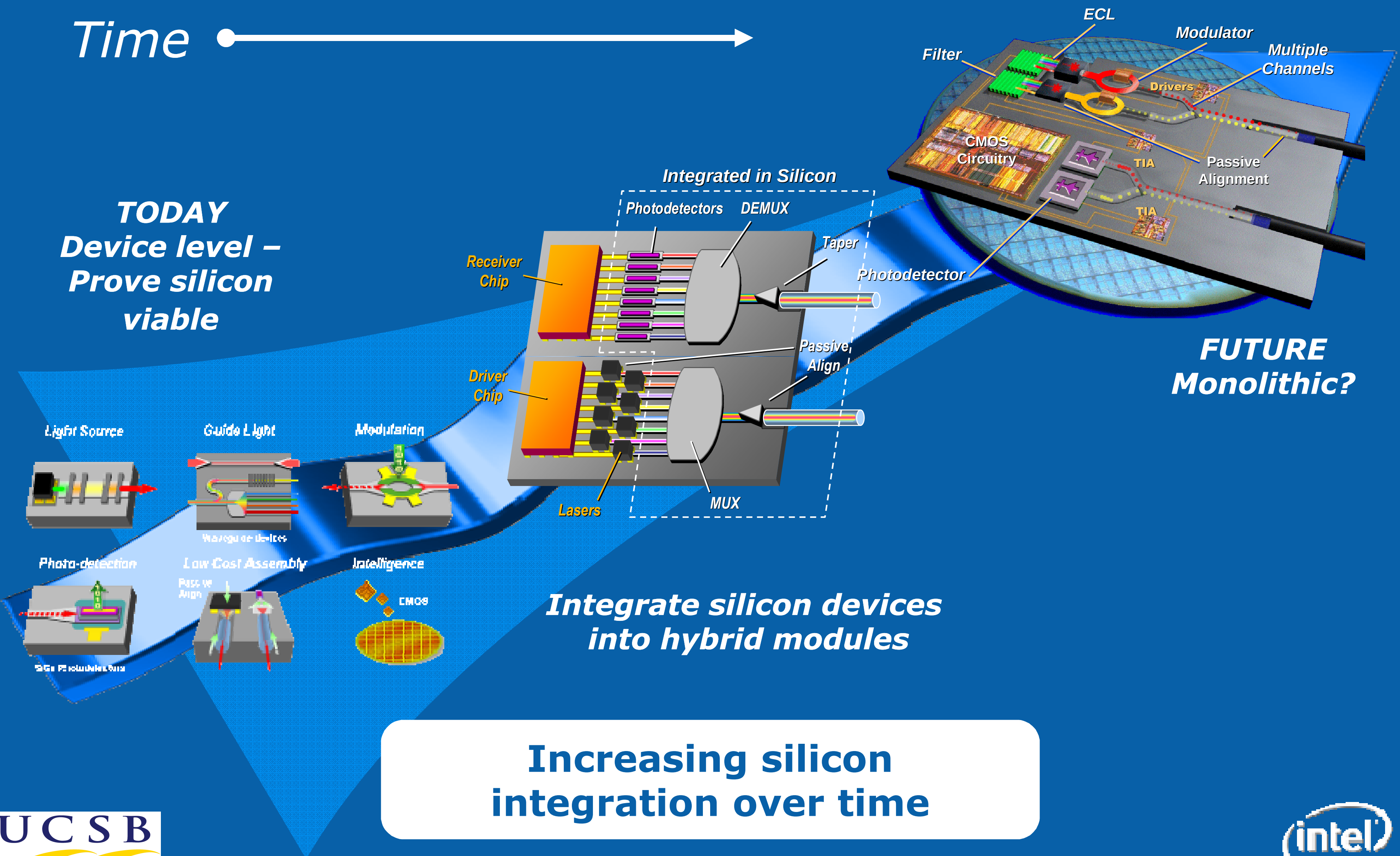
Electrically Pumped Hybrid Silicon laser
(September 2006)

1GHz *(Feb ‘04)*
10 Gb/s *(Apr ‘05)*

First: Innovate to prove silicon is a viable optical material

Integration Vision

Time



TODAY
Device level – Prove silicon viable

FUTURE
Monolithic?

Integrate silicon devices into hybrid modules

Increasing silicon integration over time

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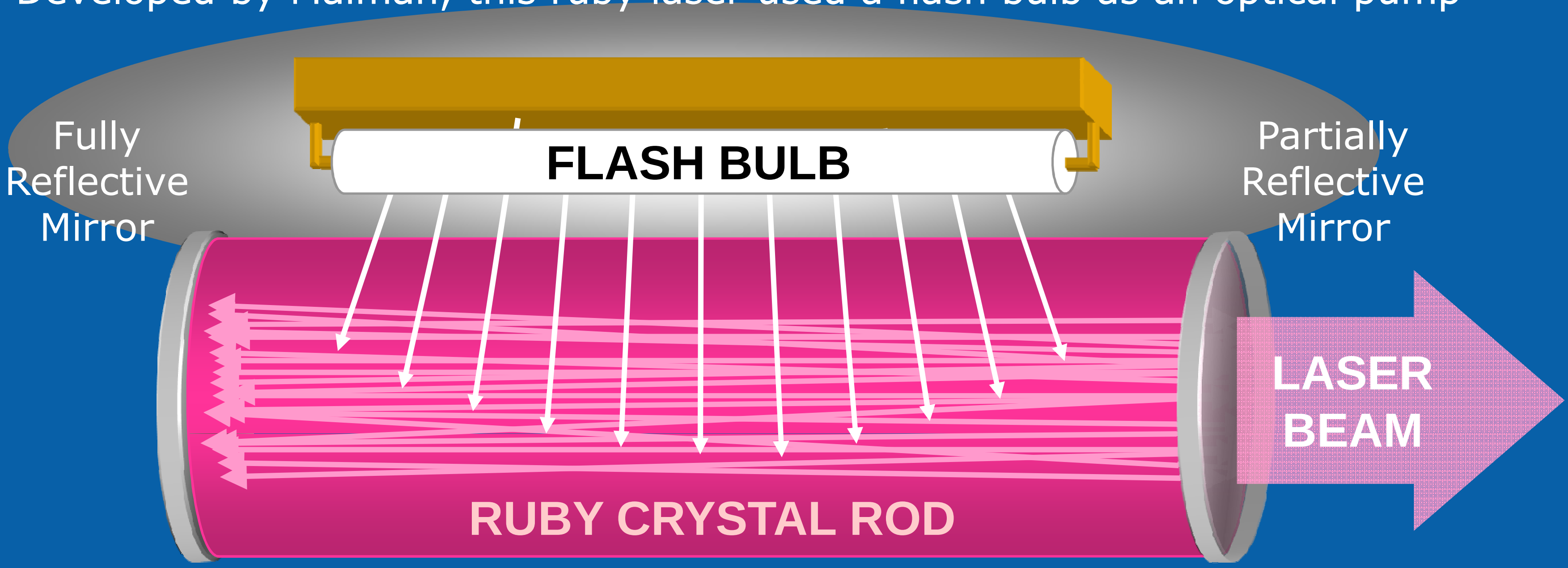
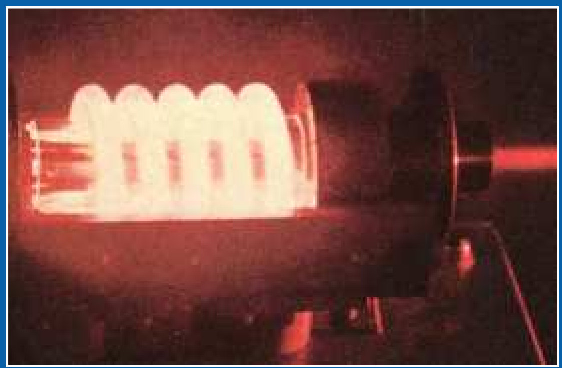
The First Laser

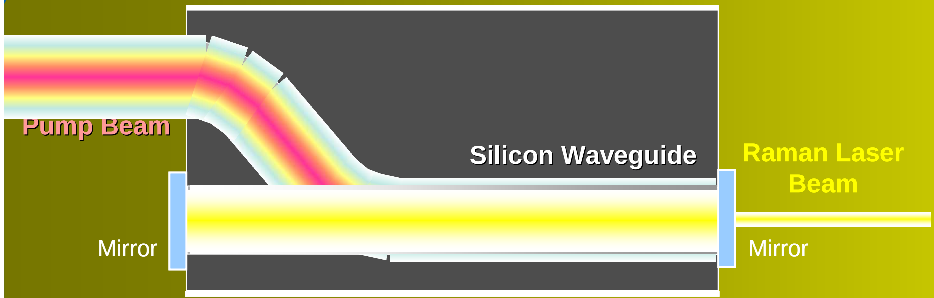
Developed by Maiman, this ruby laser used a flash bulb as an optical pump





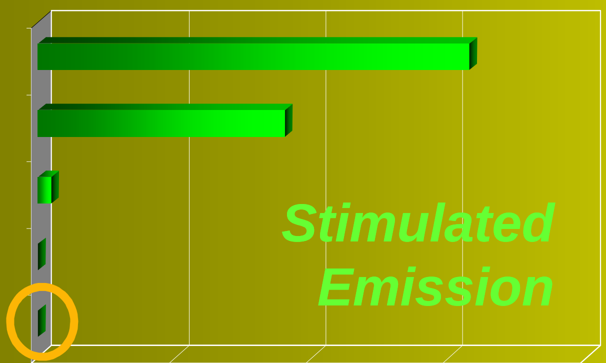
Published in *Nature*, August 6, 1960

Raman Laser
Announced in Feb 2005



<u>First CW silicon laser</u>
- Research Breakthrough
- Based on the Raman effect
- Optically pumped

Radiative recombination coefficient (10-12cm3/s)



<u>Want: Electrically Pumped</u>
- Silicon is an indirect bandgap material
- Poor radiative recombination coefficient
- Result: Silicon emits heat, few photons

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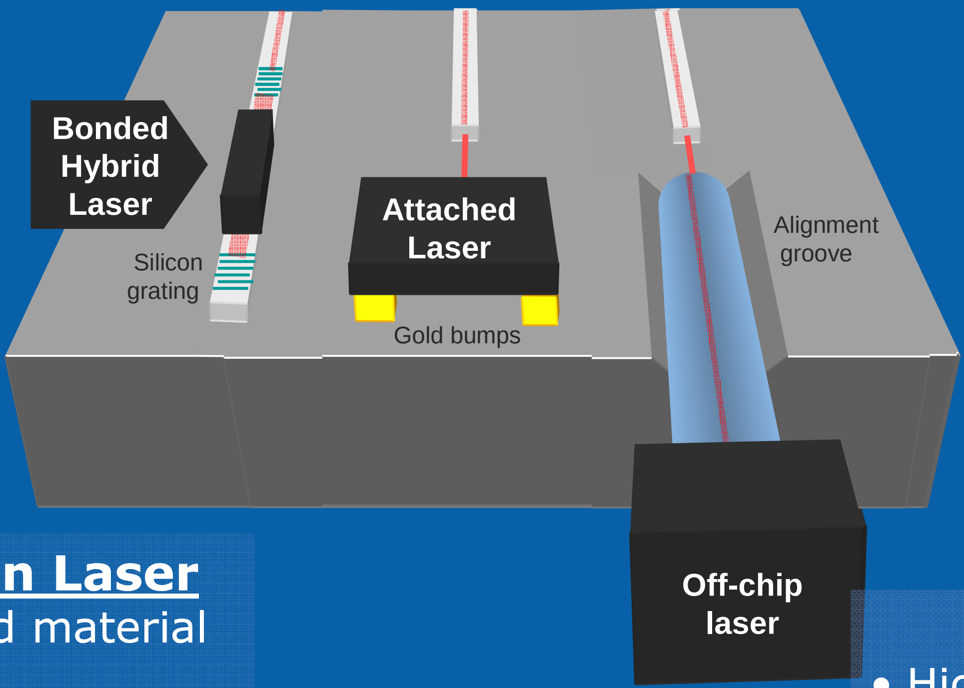
Options for Integrating Light Sources



Hybrid Silicon Laser
- Bond InP based material to Silicon
- No alignment
- Many lasers with one bonding step
- Amenable to high integration
- Potentially lowest cost

Direct Attached Laser
- Tight alignment tolerances
- Requires gold metal bonding
- Passive alignment challenges
- Less Expensive

Off-chip Laser
- High power laser required
- Requires fiber attach
- Non-integrated solution
- Expensive

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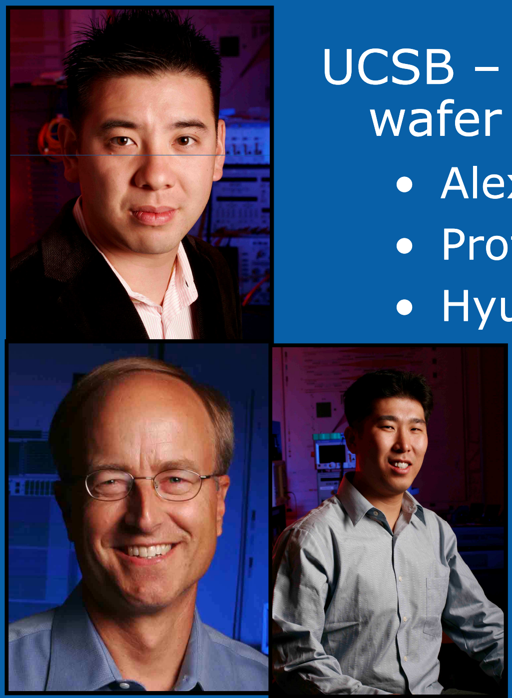
Joint Intel / UCSB Collaboration

- Goal: Create a hybrid silicon laser
- Combine the light emitting properties of Indium phosphide with light routing and manufacturability properties of silicon

Joint team and 3 year research grant



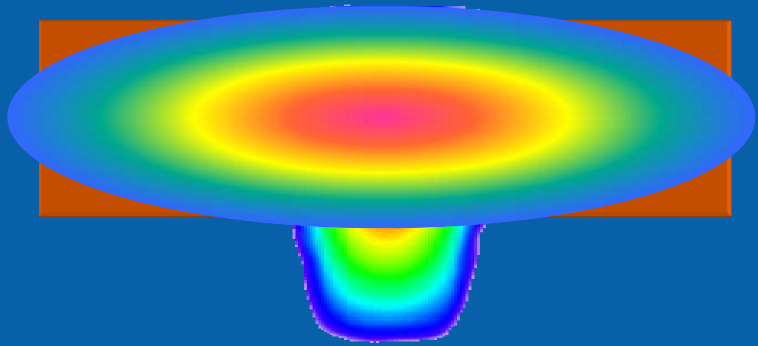
UCSB – Indium phosphide and wafer bonding expertise

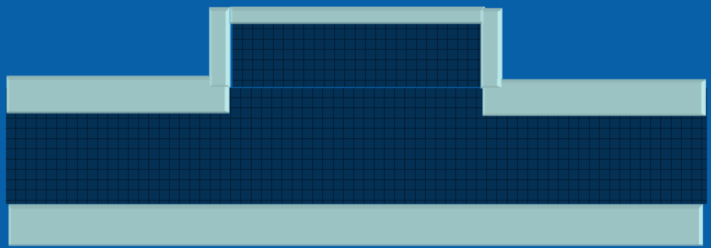
- Alex Fang (ex Intel intern)
- Professor John Bowers
- Hyundai Park

Intel – Silicon and manufacturing expertise

- Dr Richard Jones
- Oded Cohen
- Dr Mario Paniccia

Hybrid Silicon Laser
Using Evanescent Coupling





- We start with a cross sectional view of an Indium Phosphide waveguide
- When a voltage is applied to the InP it will begin to emit light
- If we bring a silicon waveguide up to the InP, light will couple into the Si waveguide
- This is evanescent coupling

Challenge: How do you bond these two materials together?

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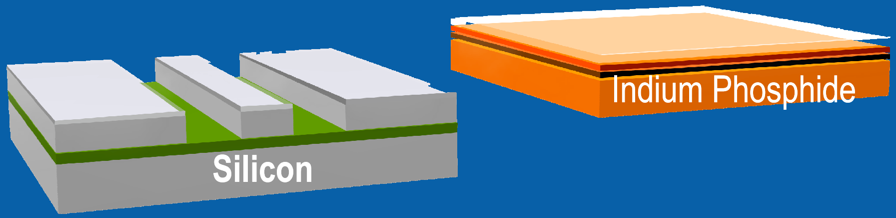
Bonding Process



The Hybrid Silicon Laser used a unique bonding technique

- **Previous attempts used crystal growth**
  - Difficult to overcome lattice mismatch/threading dislocation
  - Causes poor performance
- **Benefits of the UCSB/Intel approach**
  - Removes issue with lattice mismatch
  - Plasma process produces ~25 atom thick "glass-glue"
  - This "glass-glue" efficiently bonds the two materials
  - Low temperature manufacturable process

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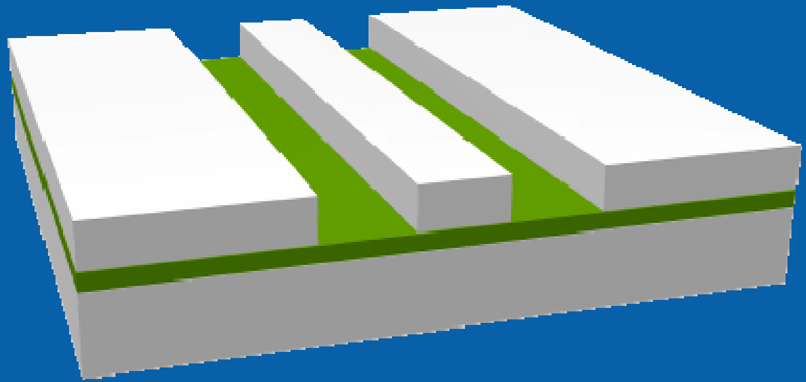
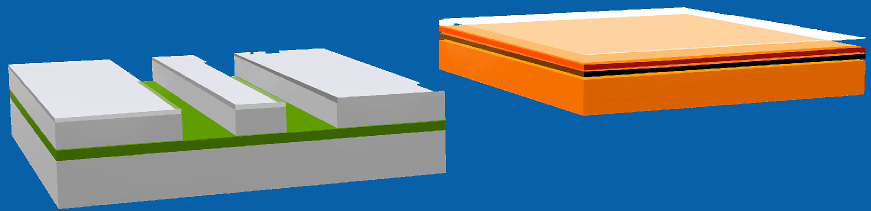
Process Animation

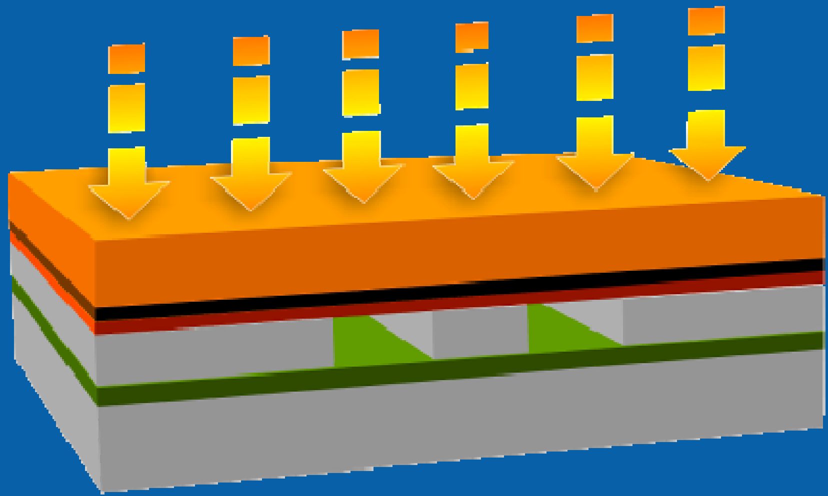


1) A waveguide is etched in silicon

2) The Indium phosphide is processed to make it a good light emitter



3) Both materials are exposed to the oxygen plasma to form the “glass-glue”



4) The two materials are bonded together under low heat

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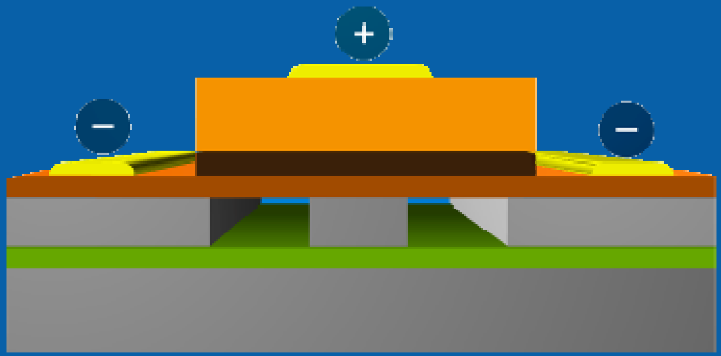
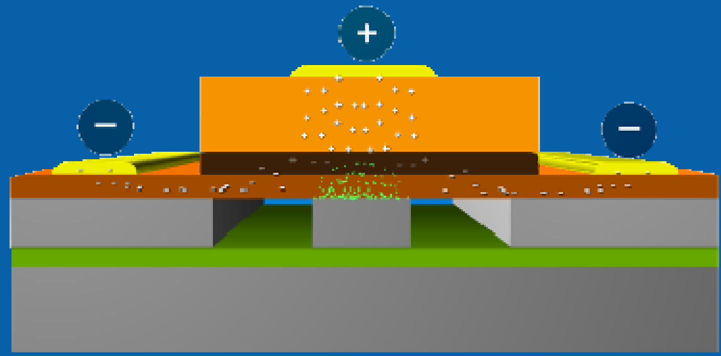
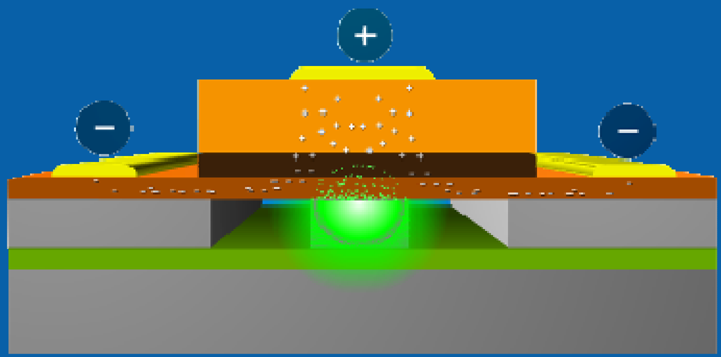
Process Animation



5) The Indium phosphide is etched and electrical contacts are added



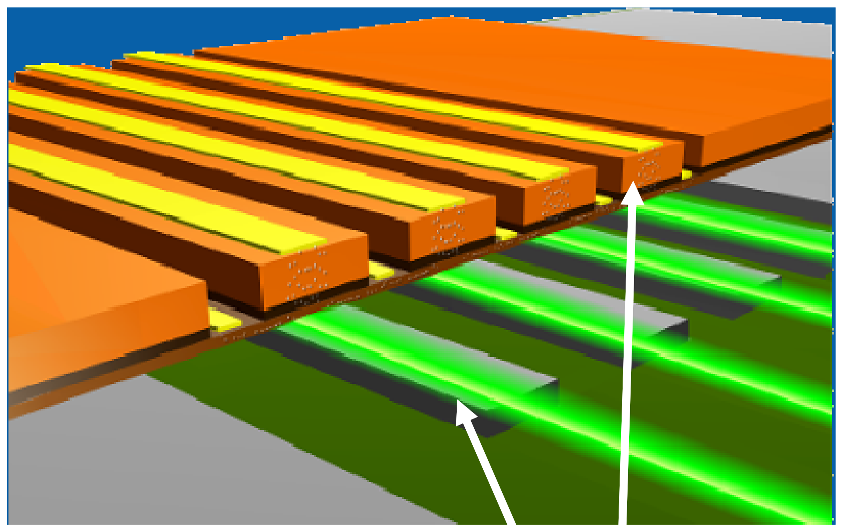
6) Photons are emitted from the Indium Phosphide when a voltage is applied



7) The light is coupled into the silicon waveguide which forms the laser cavity. Laser light emanates from the device.

Hybrid Silicon Laser

How we create a laser in silicon



- The Indium Phosphide emits the light into the silicon waveguide
- The silicon acts as laser cavity:
  - Silicon waveguide routes the light
  - End Facets are reflectors/mirrors
  - Light bounces back and forth and get amplified by InP based material

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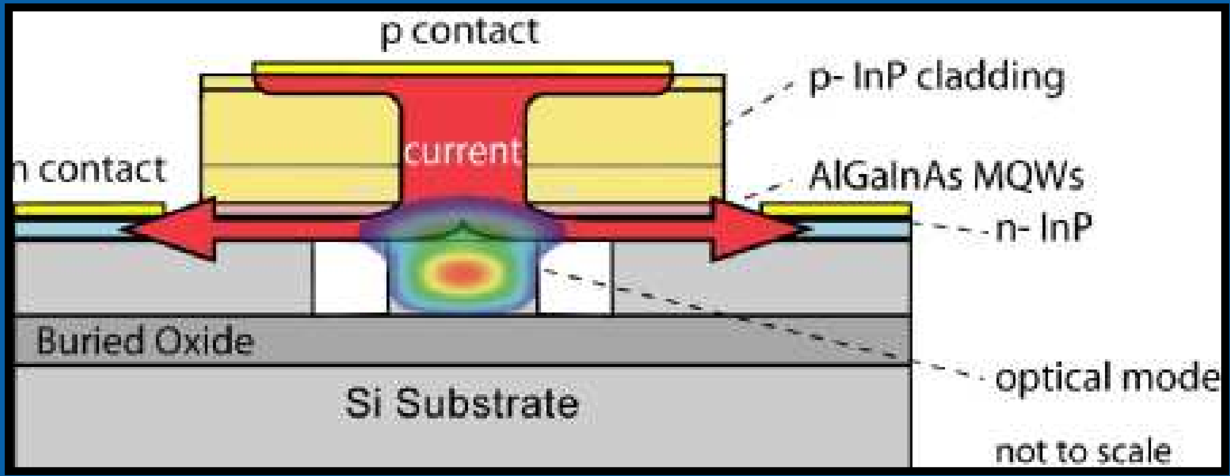
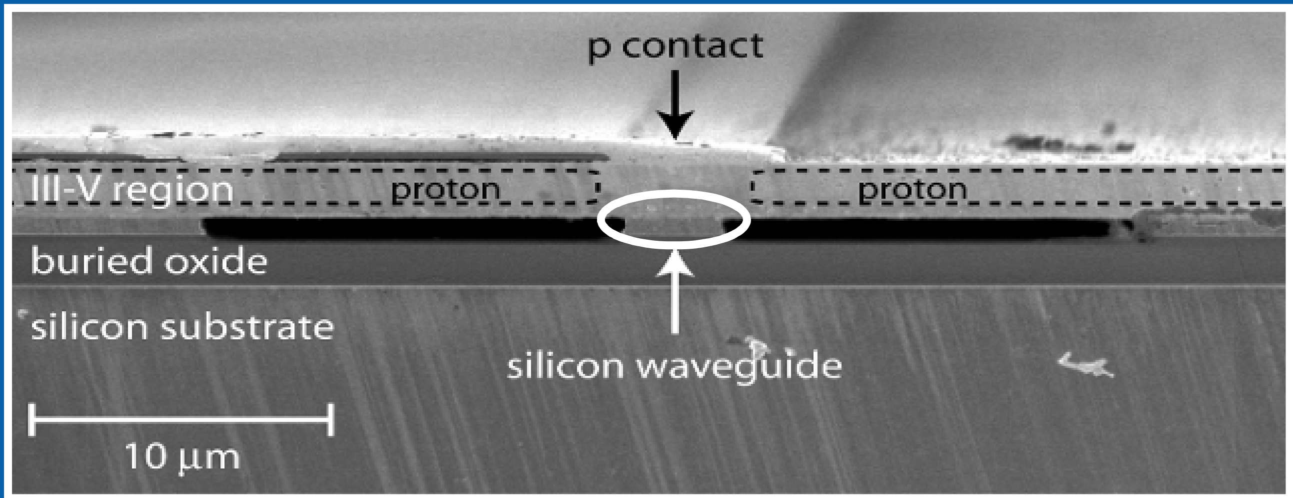
Hybrid Laser Structure

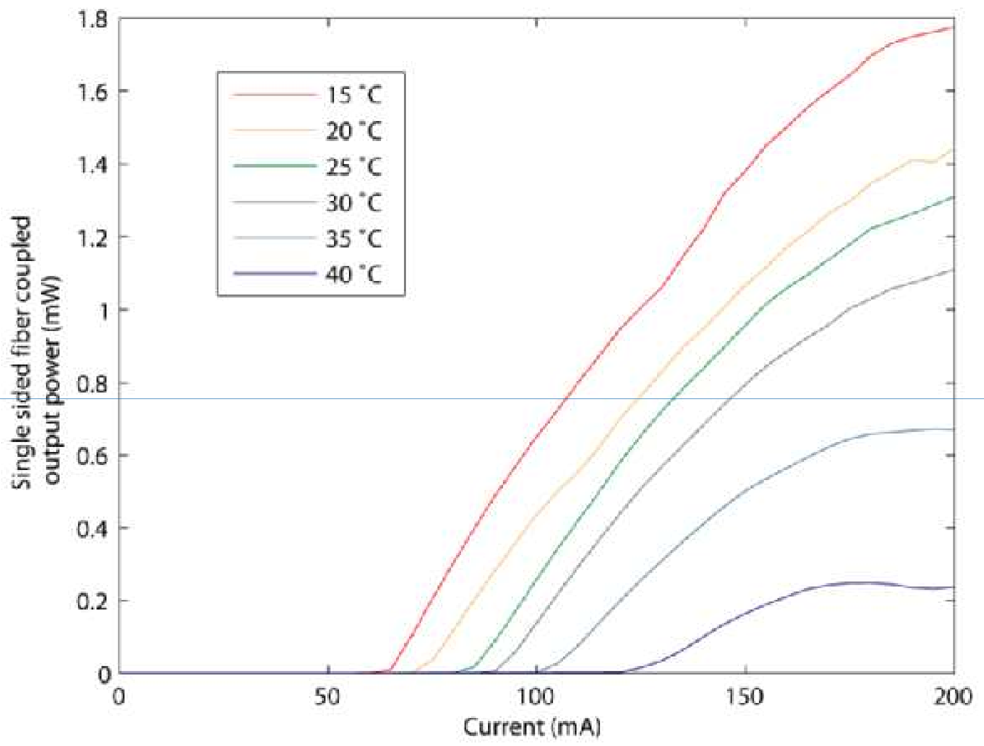




SEM (Scanning Electron Microscope) Photograph

First Electrically Pumped CW Lasing

Measured Laser output power vs current



Threshold Voltage = 2V

Threshold Current

- At 65 mA with plans to get to ~ 20 mA

Output power

- At 1.8 mW, Good for optical interconnects

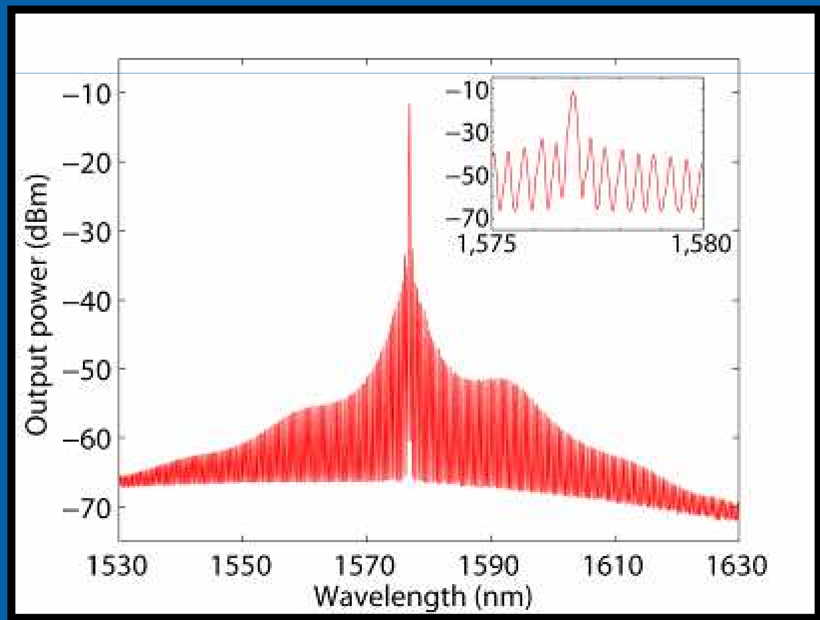
Temperature

- Operating at 40 C with plans for > 70 C

Initial testing shows good performance

Electrically Pumped Laser Wavelength

- <u>7 Hybrid Silicon Lasers</u>
  - All fabricated with a single bond step
  - Up to 36 lasers are on one die



- **Lasing Output at 1577nm**
  - This is adjustable via modifying the silicon waveguides

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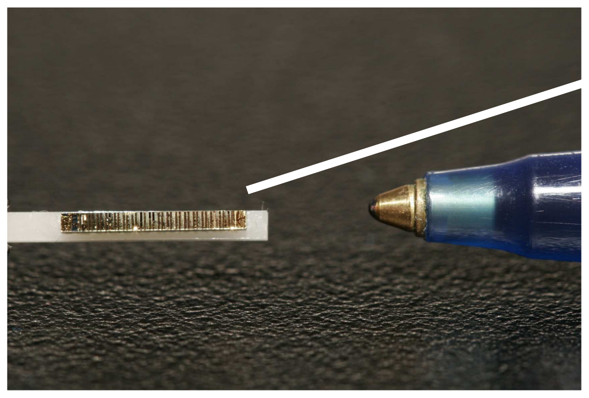
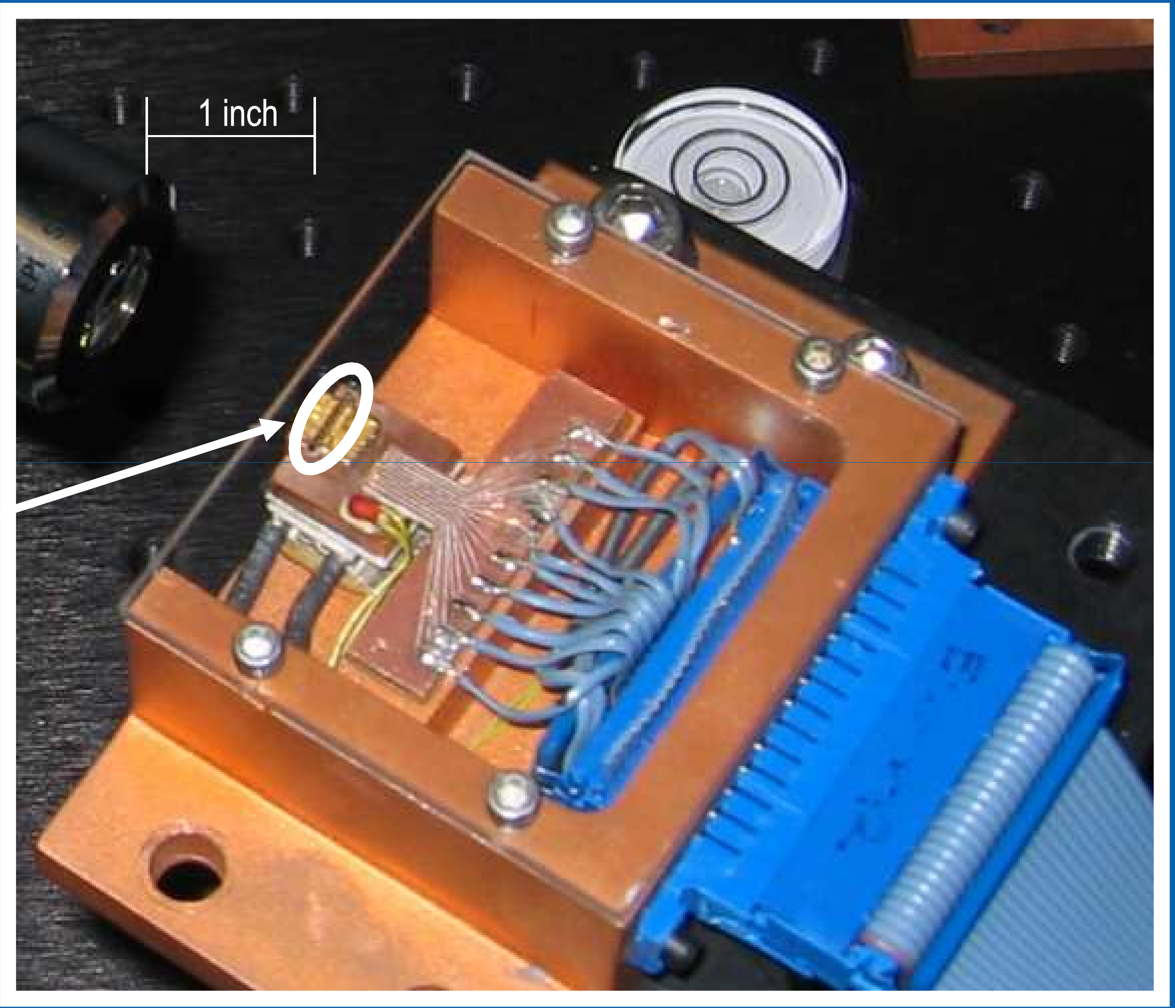
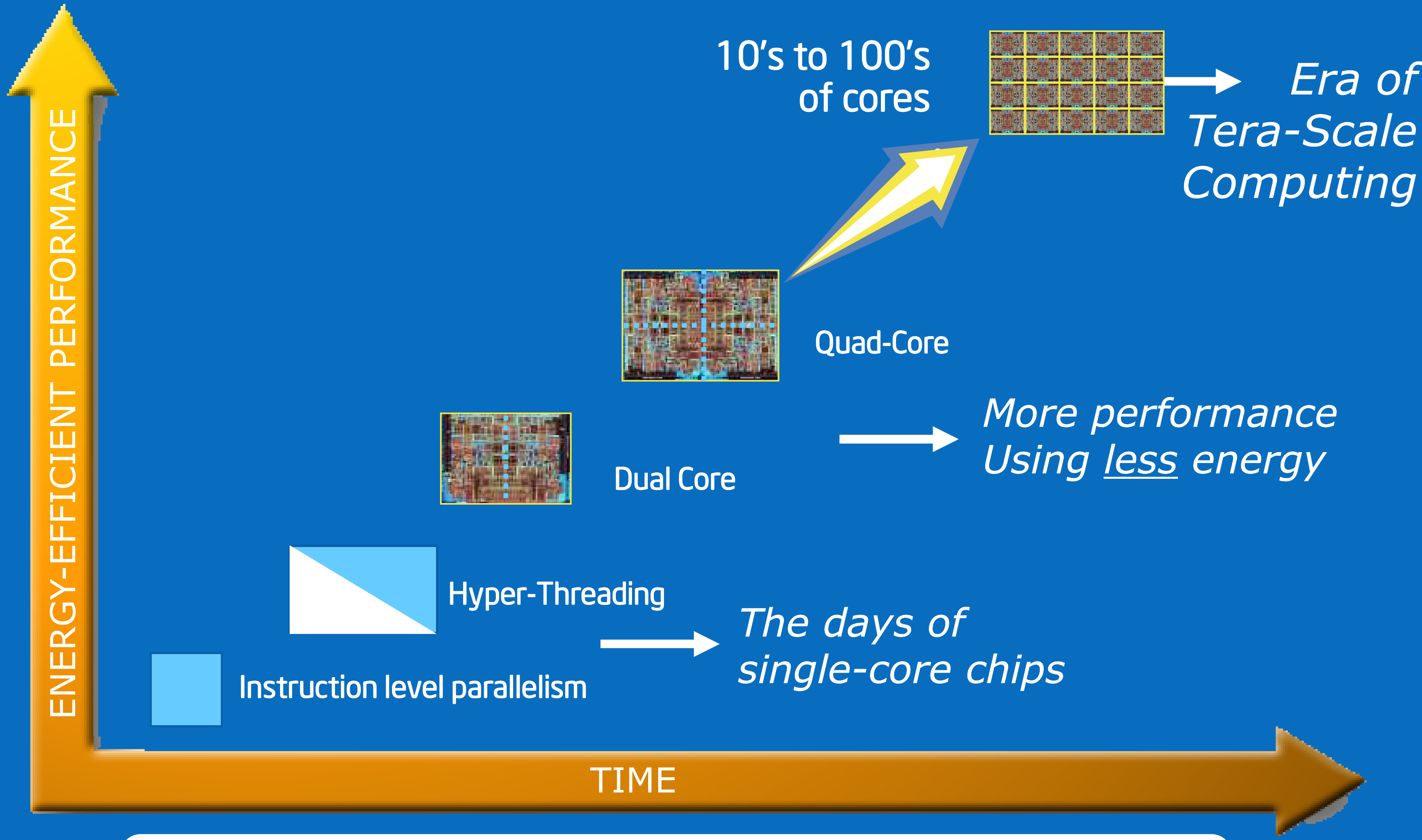
Silicon Hybrid Laser



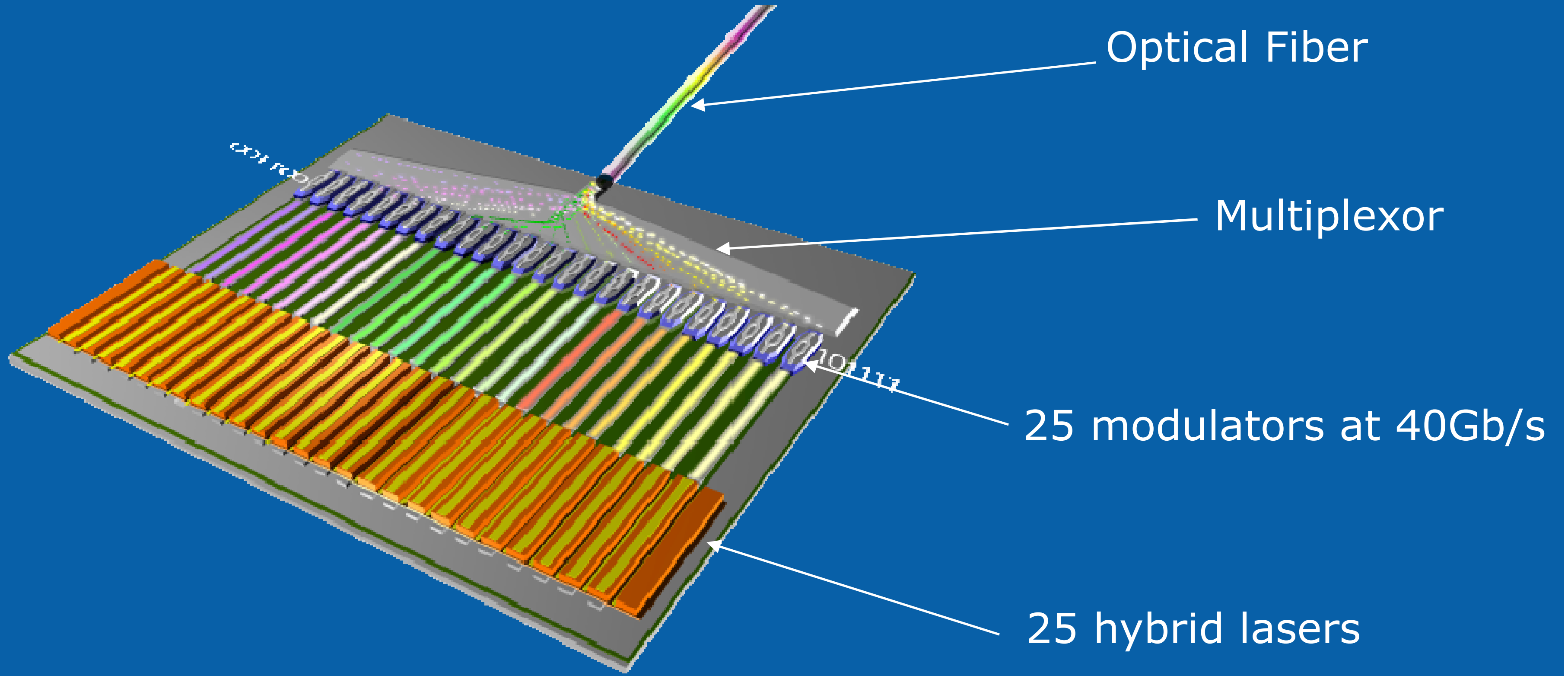


Tera-leap to Parallelism:



All this compute capability may require high speed optical links

High Integration



An future integrated terabit per second optical link on single chip

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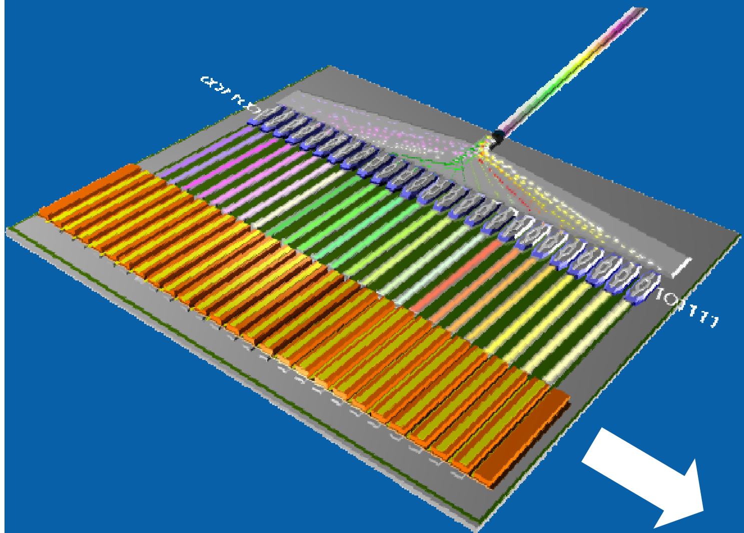
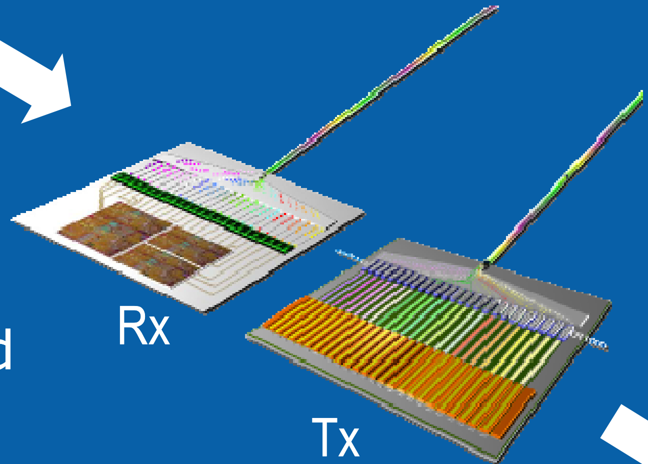
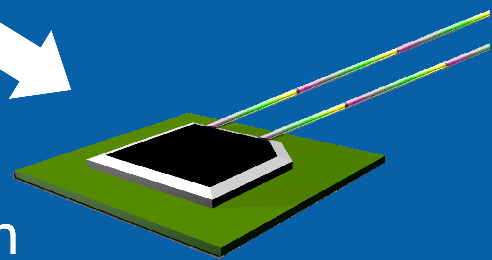
Integrating into a Tera-scale System



This transmitter would be combined with a receiver





Which could then be built into an integrated, silicon photonic chip!!

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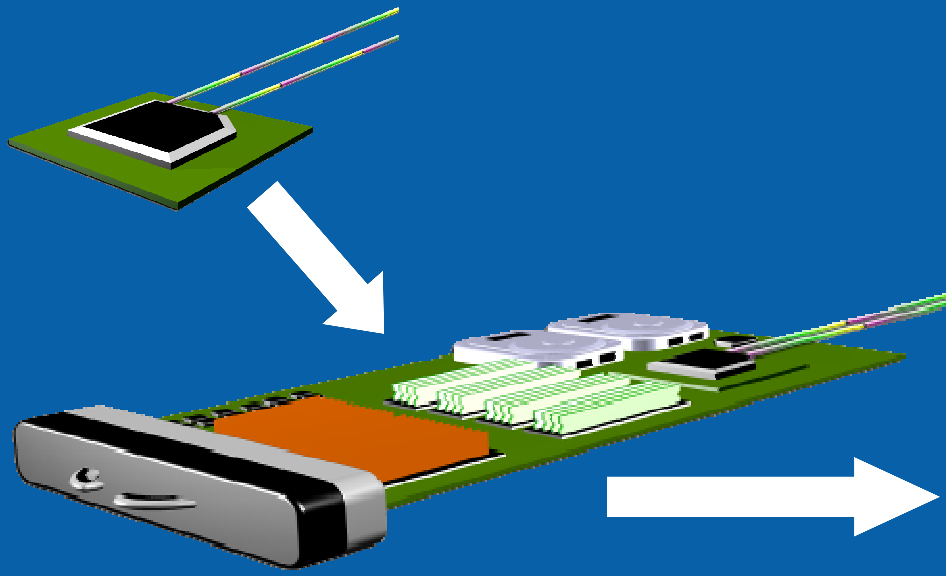
Integrating into a Tera-scale System



This integrated silicon photonic chip could then be integrated into computer boards

And this board could be integrated into a Tera-sca system

Summary

- Research Breakthrough: 1st Electrically pumped Hybrid Silicon Laser
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  - Combines the light emitting capabilities of Indium phosphide with the high volume, low cost capabilities of silicon
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Acknowledgements: UCSB and Professor Bowers would like to thank Jag Shah and DARPA for funding some of this research.