Optical Interconnects: Trend and Applications

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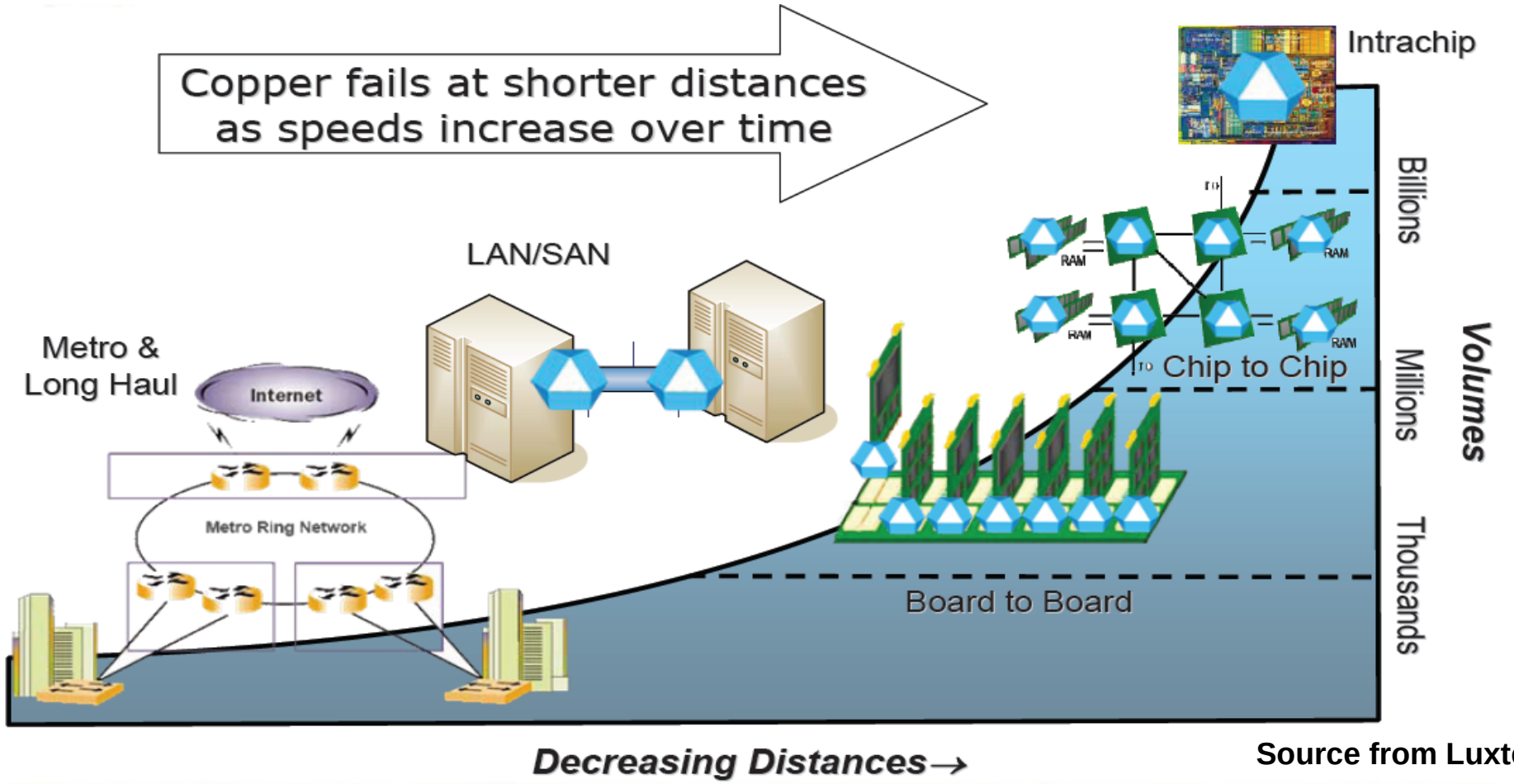
OUTLINE

- ✓ **Background and Motivation**
- ✓ **Trends of Optical Interconnects Technology and Application**
- ✓ **OI Research In EOL/ITRI**
- ✓ **Summarization**

Short Reach Optical interconnects Volumes

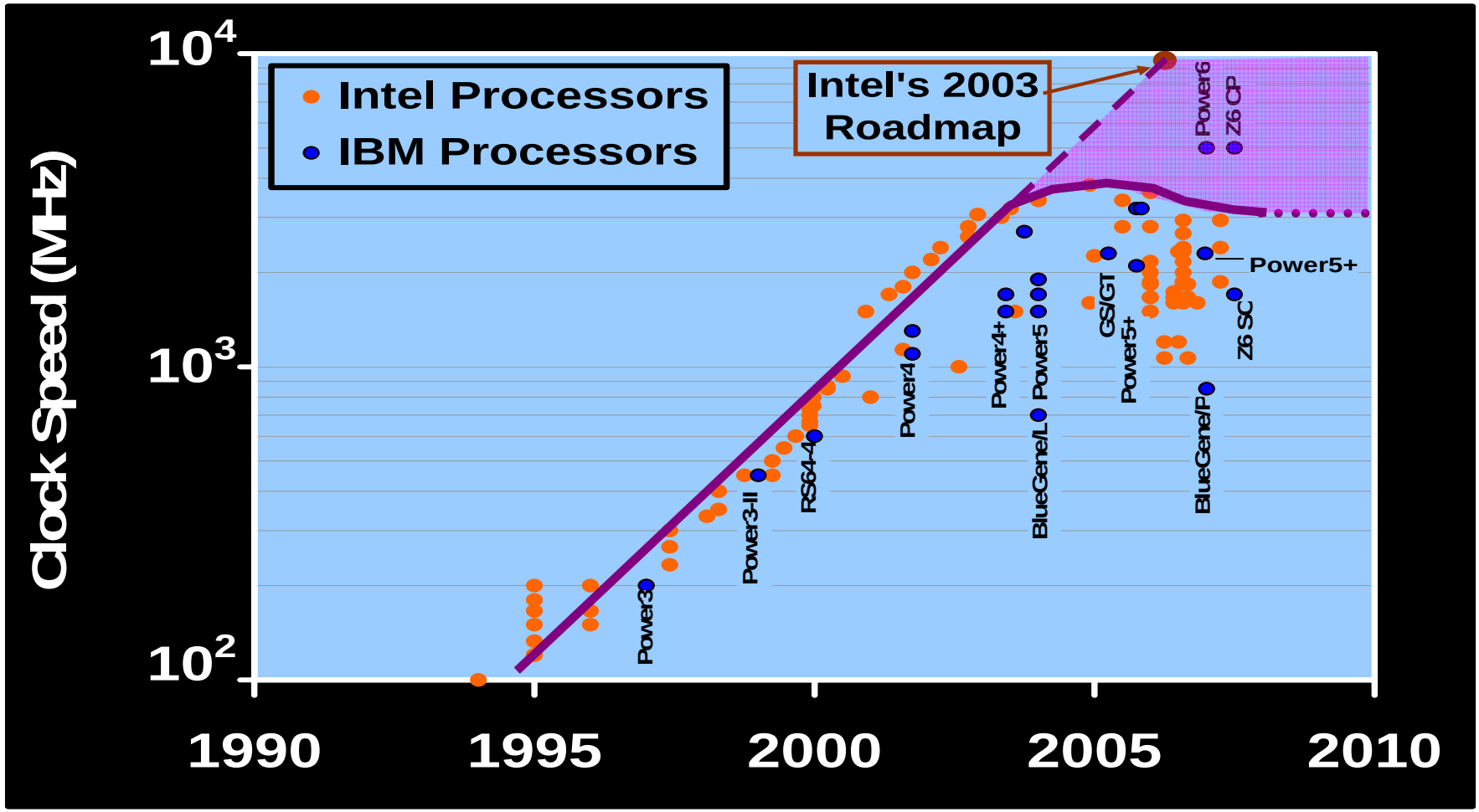


Source from Luxtera

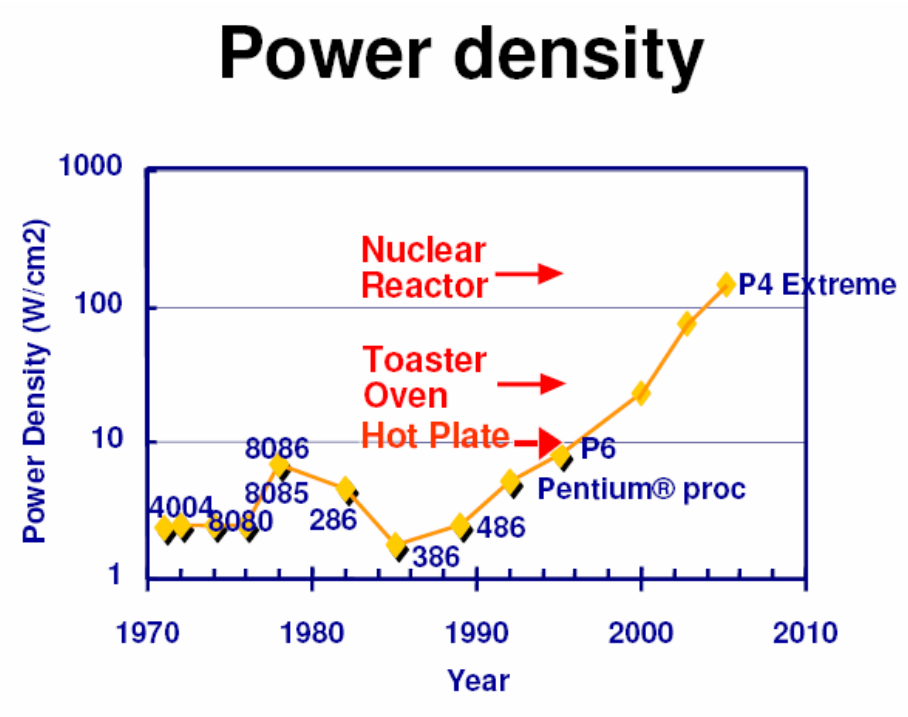
-demanding for short-range optical communication is booming, including rack to rack, board to board and chip to chip

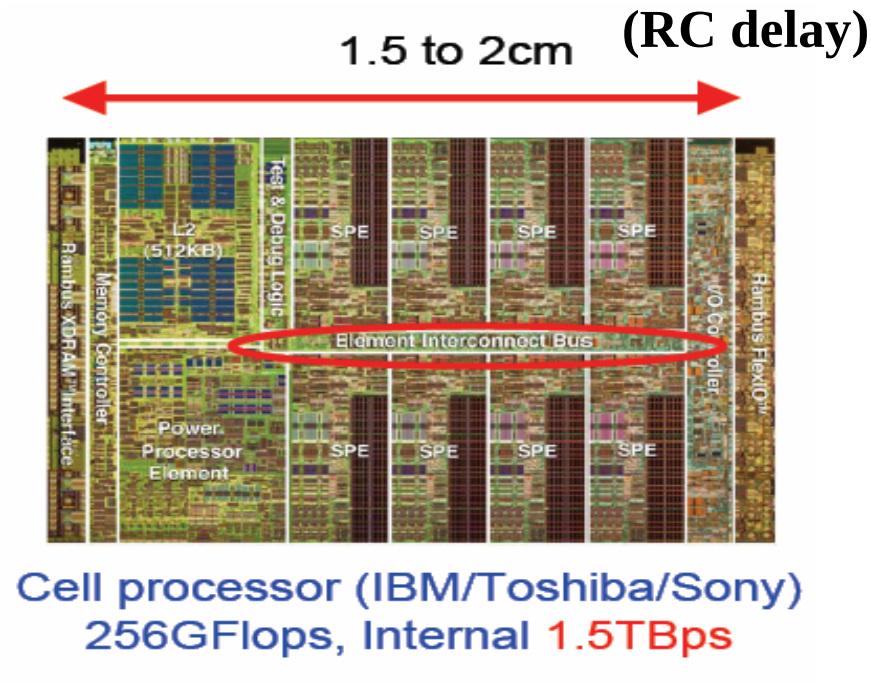
Microprocessor Clock Speed Constraints

Power constrain frequency scale-up: low power multicores replace single high-power core



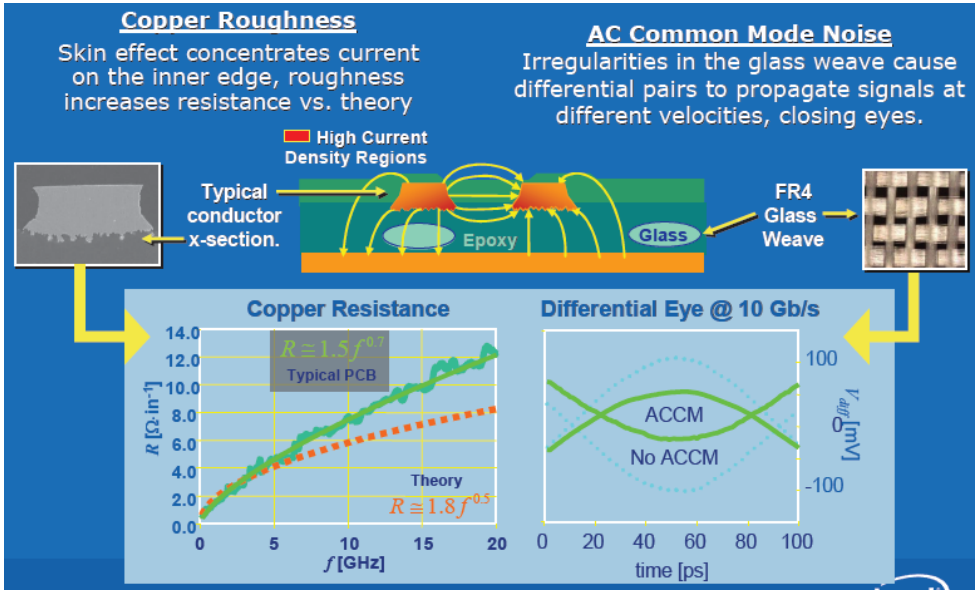
CPU Moore' Law Scaling Bottleneck



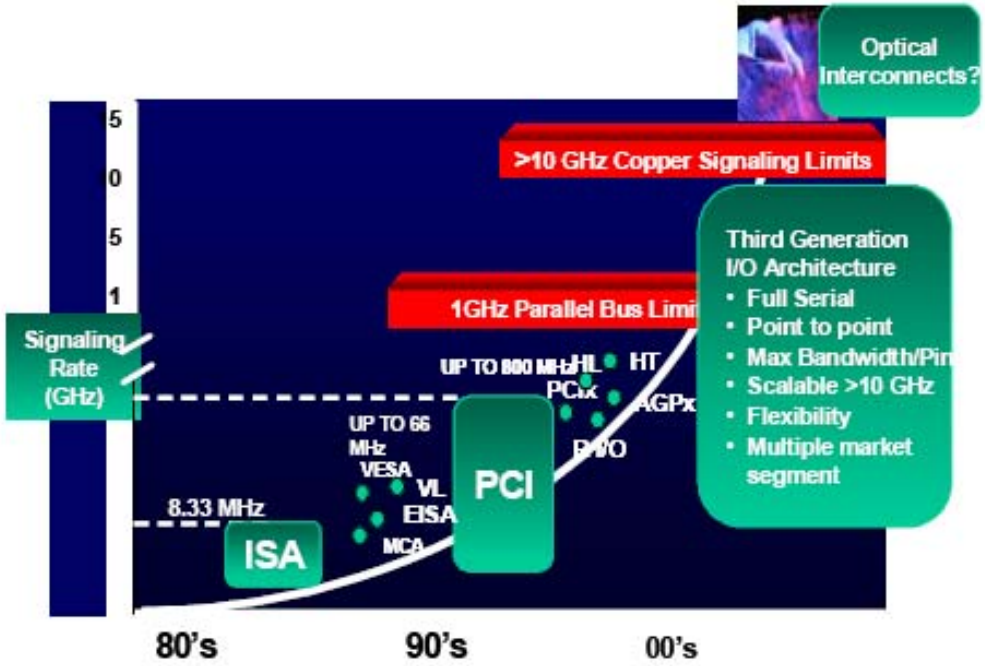


-Thermal problem limits CPU clock rate, and performance.
-Multi-core solution results in larger RC delay.

Electrical Interconnects Limits on PCB



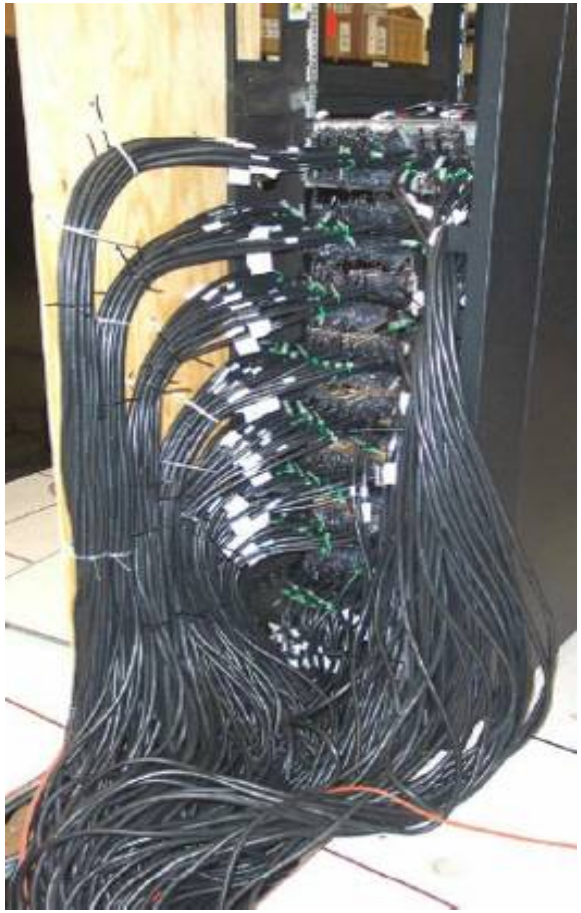
Source from Intel

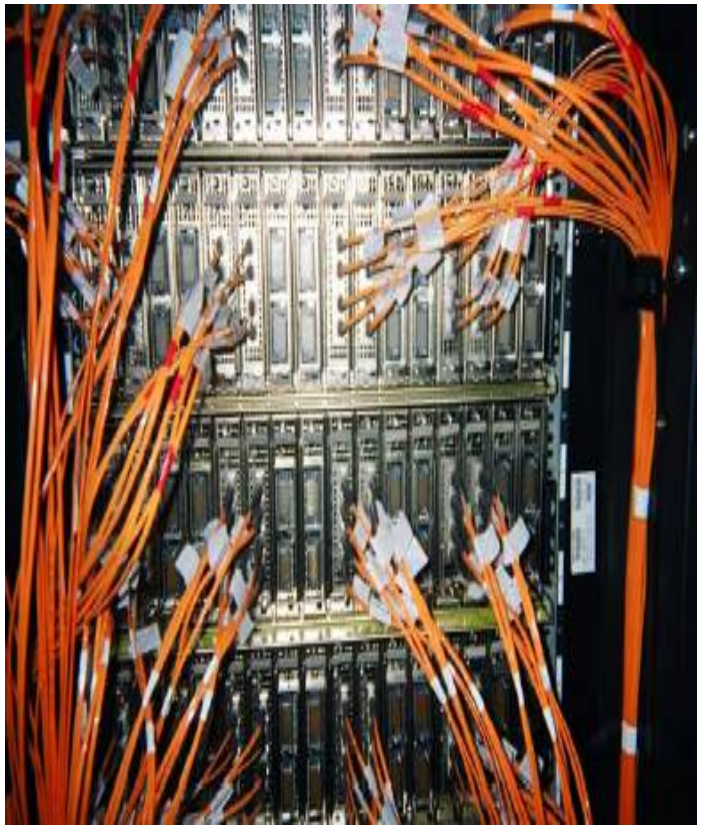


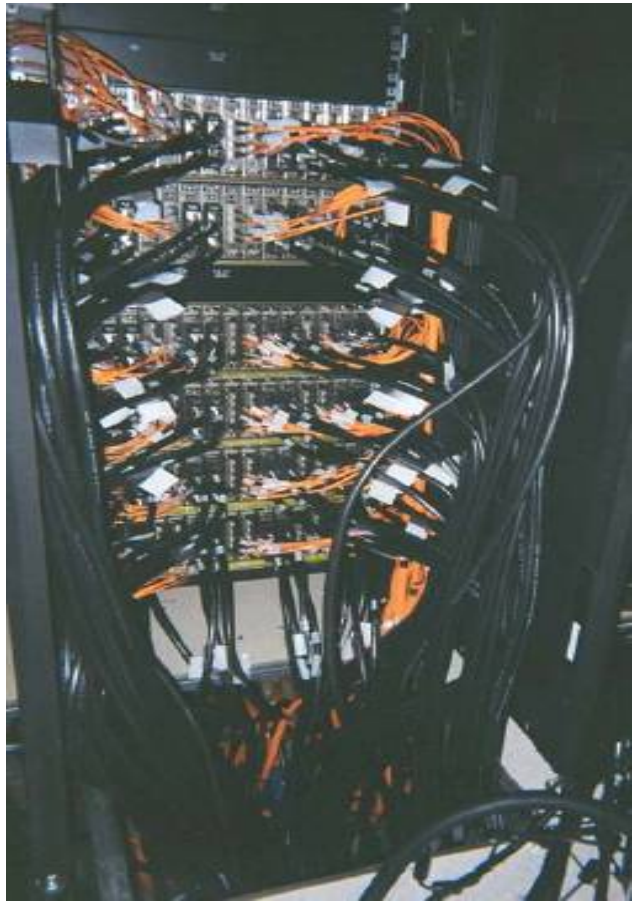
Source from Intel, 2004

-Beyond 10GHz, copper interconnects on FR4, become bandwidth limited.
-It is due to frequency depend loss, the skin effect and the dielectric loss .
-The effect of reflection and cross talk on electrical interconnect are also challenge to designer.

Cable Management – Weight and Cost of Copper



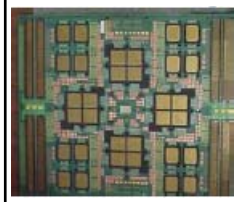
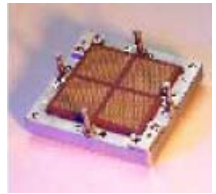
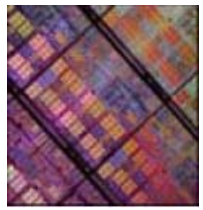




Latency is an issue for 10G copper above 10m with encoding

Optical Interconnects Hierarchy

When & where: Optical interconnects trends from Long to Short in link Hierarchy

	Internet, Wide Area Network	Local Area Network	Rack-to-Rack	Board-to-Board	On Board	On-MCM	On-Chip
							
Distance	Multi-km	10-2000m	30+m	1m	0.1-0.3m	5-100mm	0.1-10mm
Number of lines	1	1-10	~100	~100-1000	~1000	~10,000	~100,000
Use of optics	Since the 80s and the early 90s	Since the late 90s	2005	2010+	2010-2015	Probably after 2015	Later, if ever

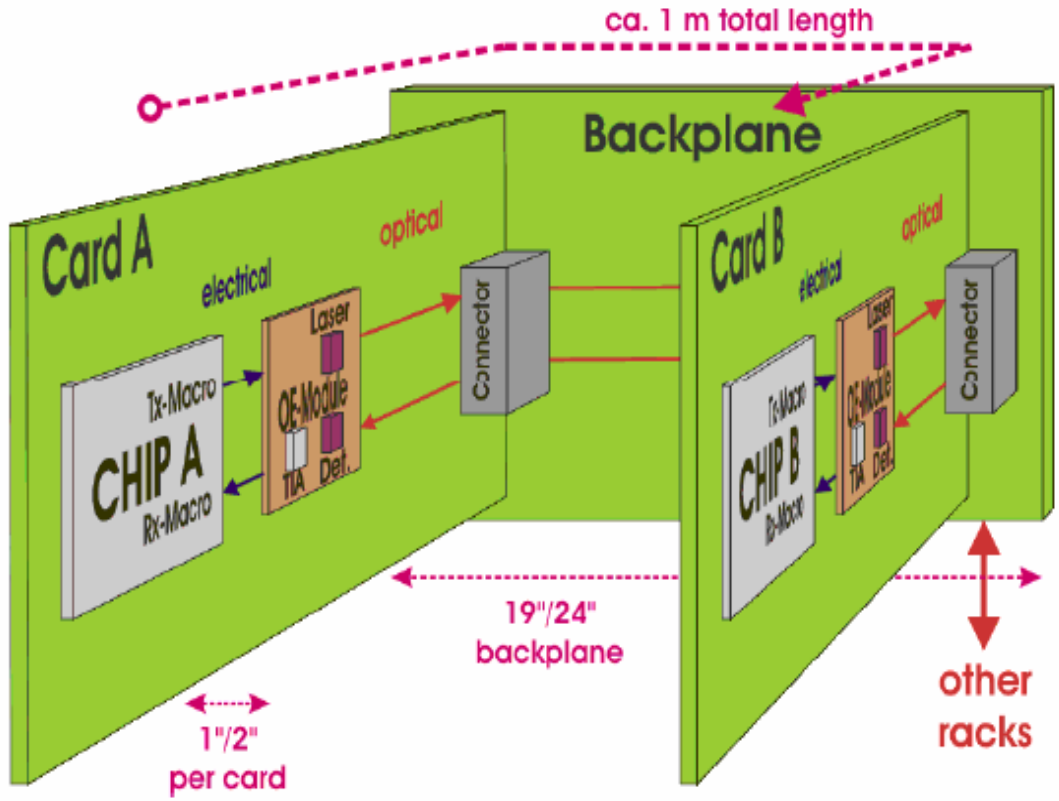
Source from IBM, 2005

Advantages of Optical Interconnects

- Highest and future-proof bandwidth
- High density integration on a low-cost board
- Lower crosstalk/coupling between sub-modules
- Simpler physical layout, efficient system architecture
- Compatible with board material and fabrication technology

Elements of Optical Interconnects

- **Electronics Chips**
- **OE Modules**
  - **Laser, PD**
  - **Driver, TIA, Post amplifier**
- **Optical Link**
  - **Fiber, Waveguide, Free space**
  - **Buried, On-Board**
- **Coupling Optics**
  - **Direct Coupling**
  - **Micro Array Lenses**
  - **45° Mirror**



Source from IBM, 2005

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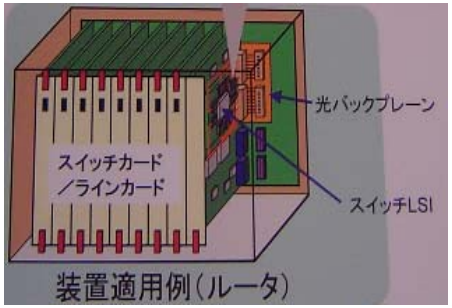
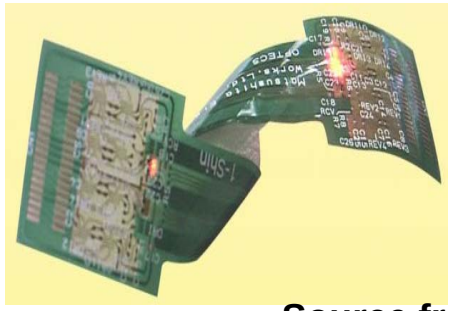
Worldwide OI Activities and Applications

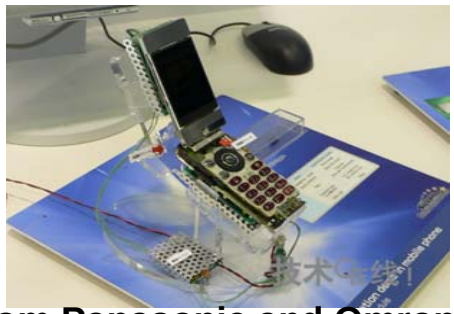
	Intel	IBM	EU-IO Project	NEC	Korea ICU
Solution	-SiOB(B2B) -FCPGA(C2C) -Silicon laser -MM Fiber Array	-Si Module -Rigid OECB	-SMT O/E Package -POF on Flex, Glass Sheet OECB	-MM Fiber Array	-MM Fiber Array and Mini- Connector -Rigid OECB
Application	Backplane, Sever, CPU	Backplane, Sever, Supercomputer	Backplane, Sever, Supercomputer	Backplane, Sever, Supercomputer	Backplane, Sever, Supercomputer

	Nokia	Samsung	Panasonic	Sumitomo Bakelite	OMRON	EOL/ITRI
Solution	-Flexible OECB	-Flexible OECB	-Flexible OECB	-Rigid OECB -Flexible OECB	-Flexible OCB	-Rigid OECB -Flexible OECB
Application	Cell Phone	Cell phone	Cell Phone, Camera	Cell Phone	Cell Phone	Backplane, Cell Phone



Backplane Applications

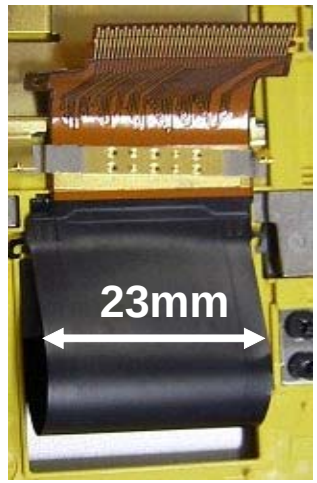




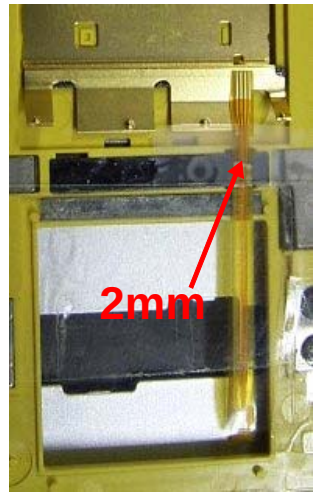
Source from Panasonic and Omron

Consumer Electronics

Copper FPC vs Flexible OECB



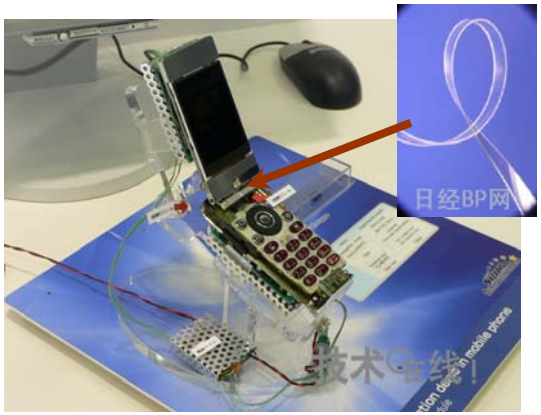
Copper FPC



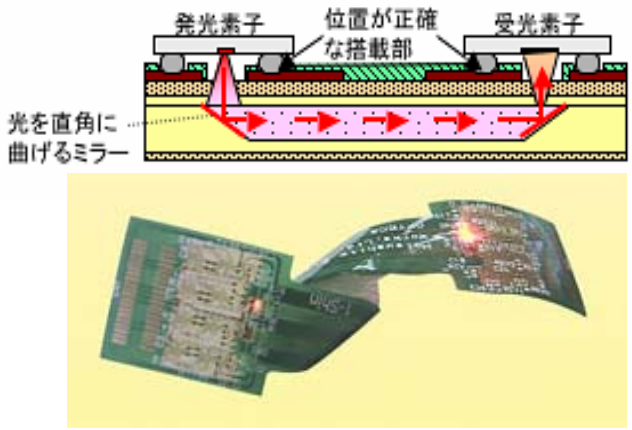
Flexible OECB

	Copper FPC	Flexible OECB	Improvements
Speed	800Mbps/Ch	2.5Gbps/Ch~10Gbps/Ch	Speed increases 3~10 times
Transmission Line	-6+ layer air-gap Flex -50+ Electrical lines	-4Channel Optical Lines, 8 Electrical Lines	-Less transmission lines -Reduce connector complexity
Size	20~30mm	2~3mm	Increase industrial design flexibility
EMS	EMI radiation and crosstalk	Eliminate EMI problem	-Reduce time and resources spent on solving EMI issues before products launch
Power Consumption	large	small	Less power consumption and thermal heat
Mechanical	Coppers easily fatigue under repeated bending	More flexible	Increase mechanical flexibility

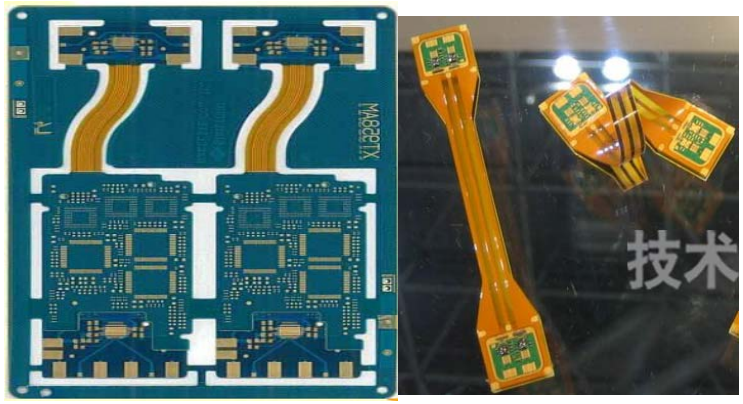
Flexible Optical Circuit Board OE Module



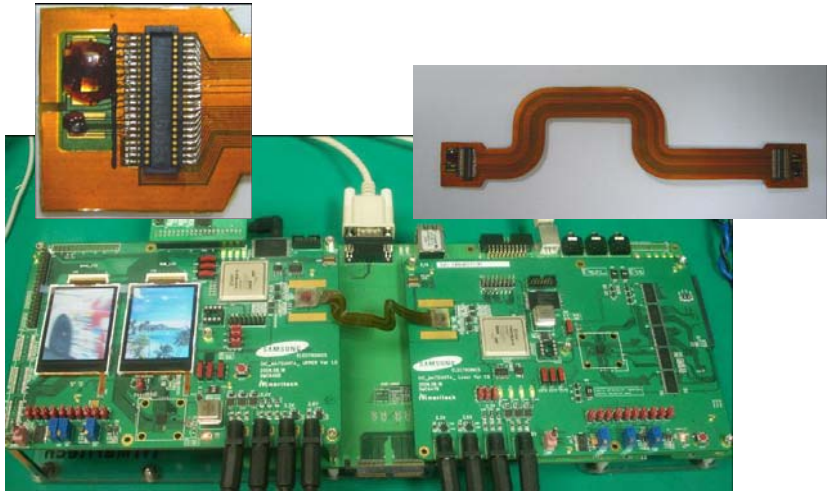
Omron(2005)



Panasonic(2005)



Sumitomo Bakelite(2006)



Samsung (SPIE, 2007)

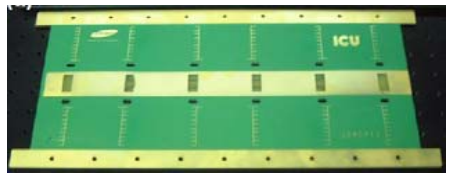
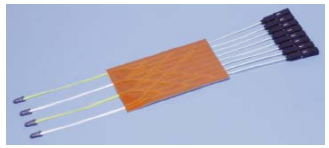
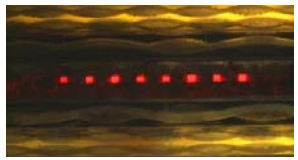
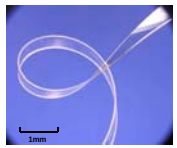
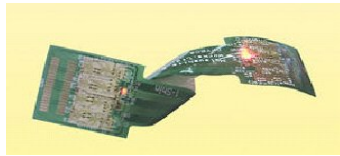
Advantages of Flexible Optical Interconnect

1. Reduce flex connector complexity
2. Eliminate EMI
3. High bandwidth potential
4. Simply layout & board lamination
   (Compliant with PCB Process)
5. Increase mechanical/industrial design flexibility
6. Compact size
7. Flexible
8. Lower power consumption

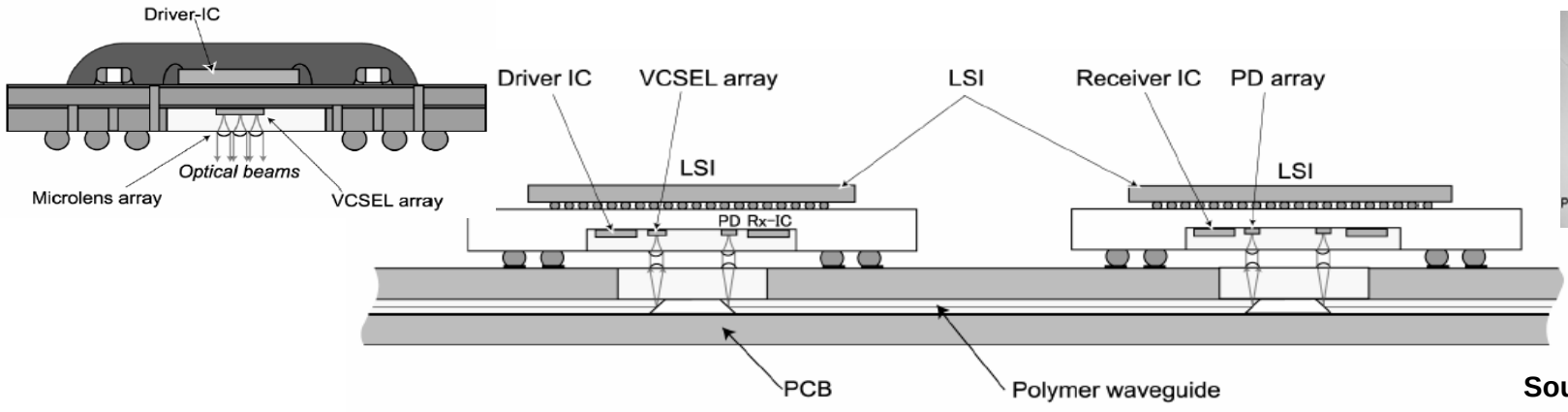
Opto-Electrical Circuit Board (OECB)

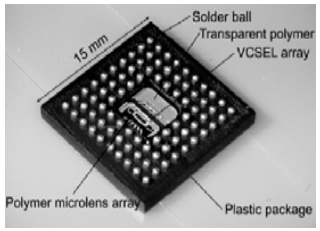
Optical circuit board = medium X substrate

medium	Substrate (construction)
fiber (silica / polymer)	Flexible substrate Incl. sheet, FPC, without
waveguide (polymer)	Rigid substrate Incl. board, PCB, without

	Rigid	Flexible
Fiber		
Waveguide		 

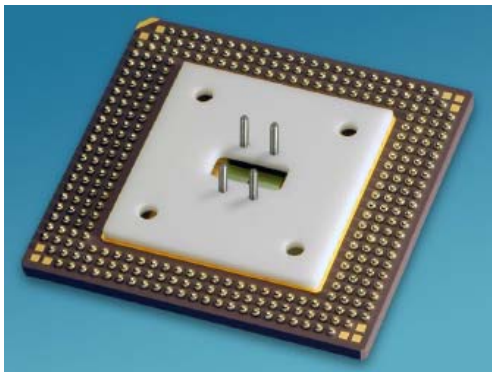
OE Module and OECB Optical Integration





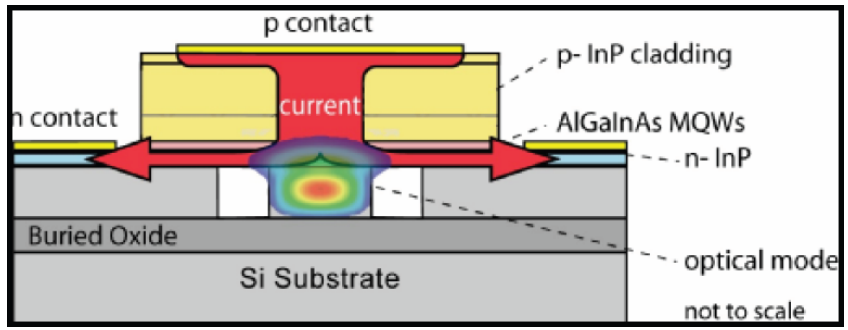
Source from NTT, 2003

SMT Compatible Optical Interface



Source from Uhgent, 2007

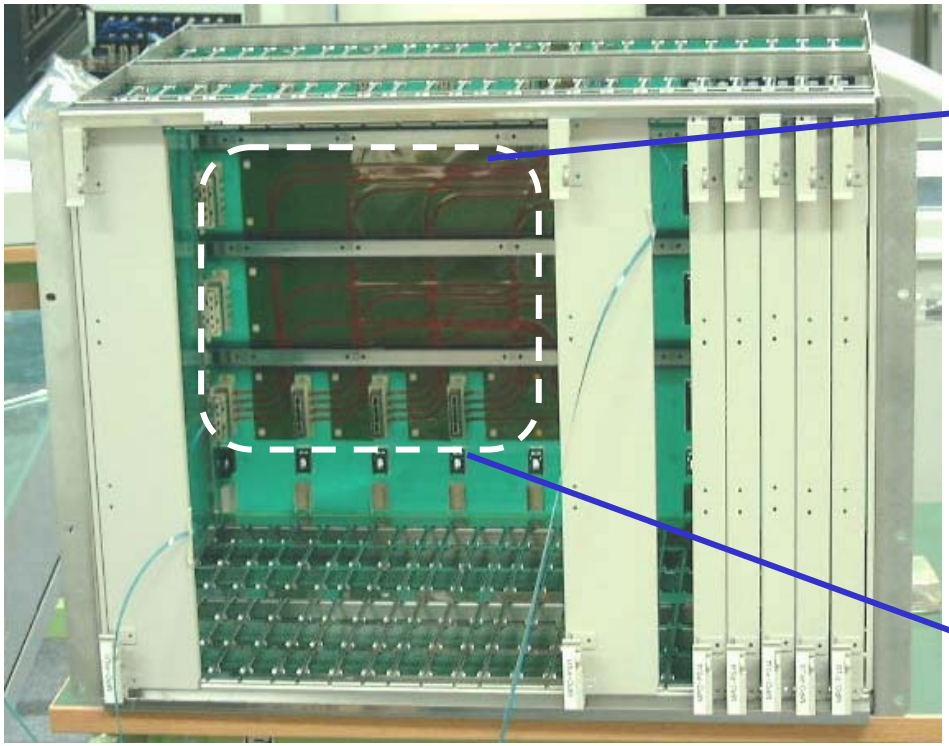
Optical Connector



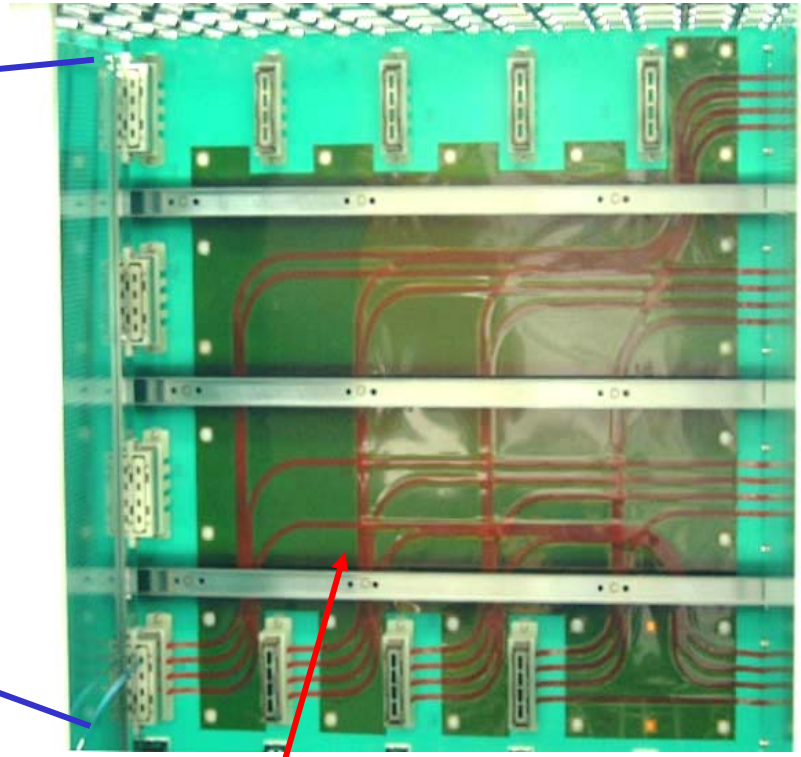
Source from UCSB, 2006

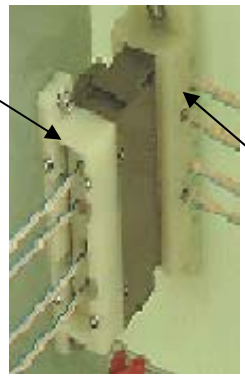
Evanescent Coupling

Optical Backplane of Fiber Flexible OECB



Optical backplane





board side

backplane side

Right angled connector

Fiber flexible OCB (192ch)

multimode fibres

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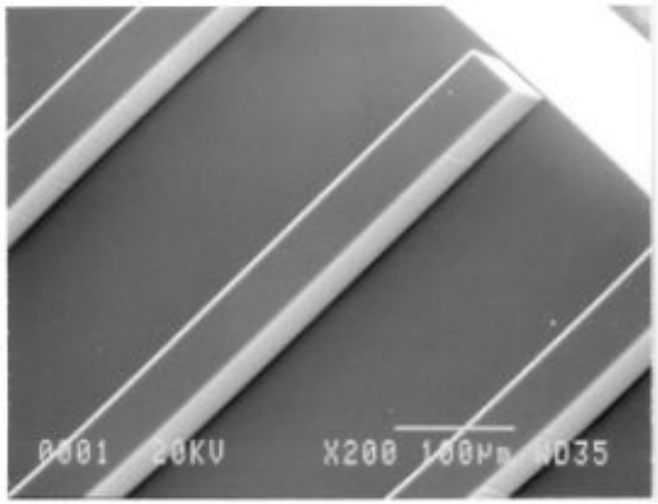
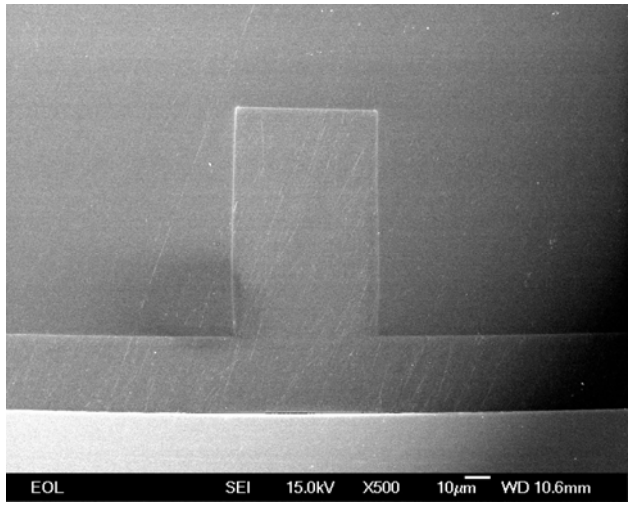
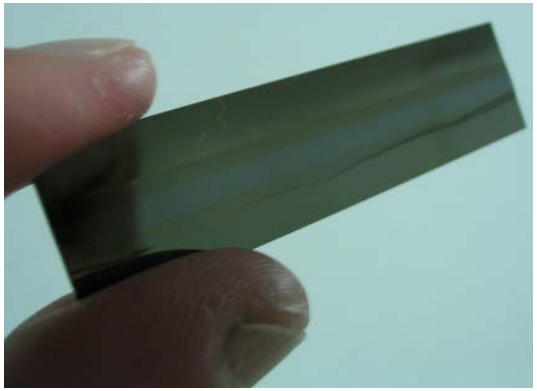
Polymer Waveguide Fabrication

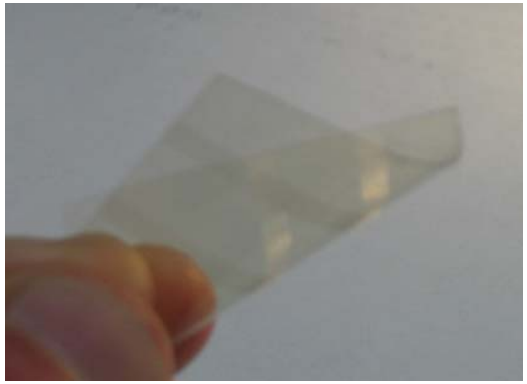




Waveguide Fabrication Using UV Photolithography

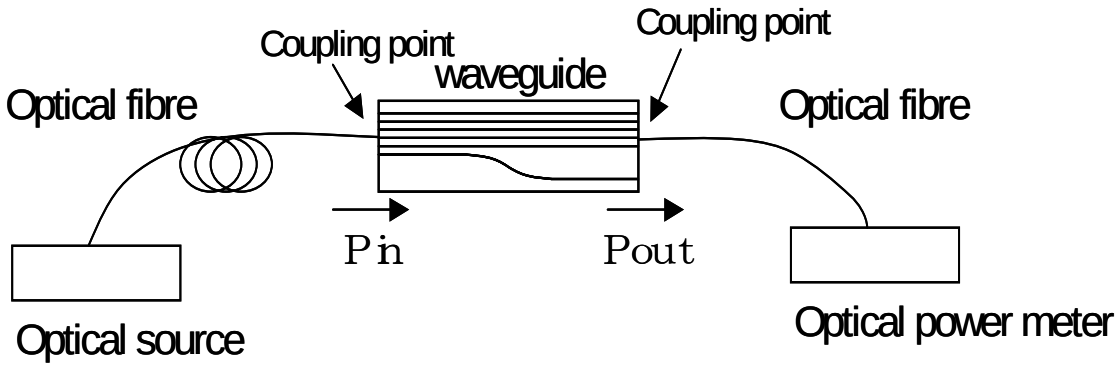


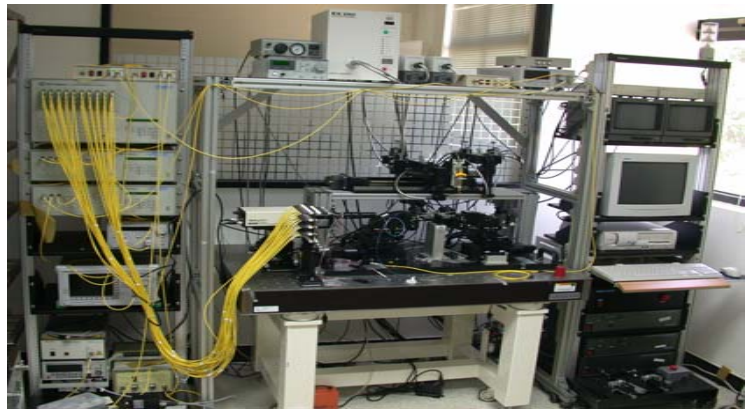
Waveguide on Silicon Substrate



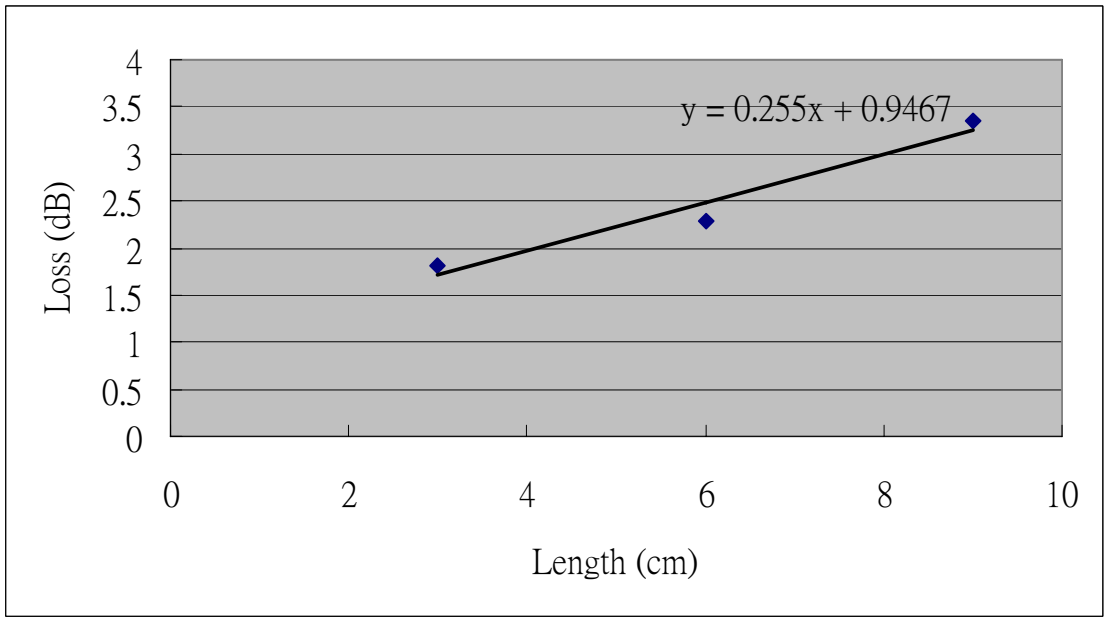
Flexible Waveguide Film

Waveguide Performance Evaluation





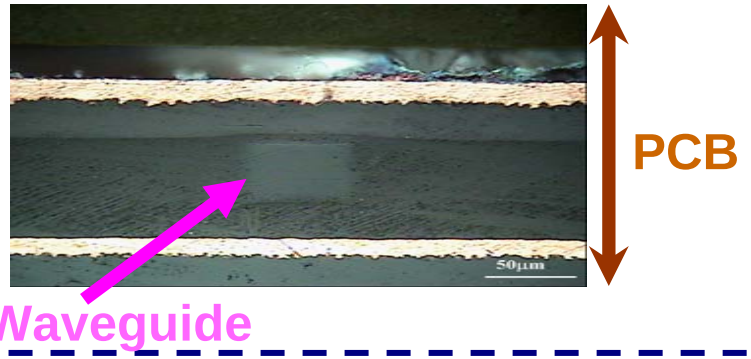
Measurement Setup



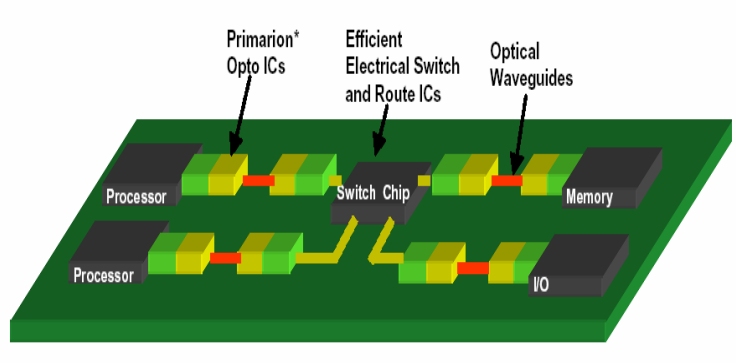
Cut back Channel loss~< 0.3dB/cm

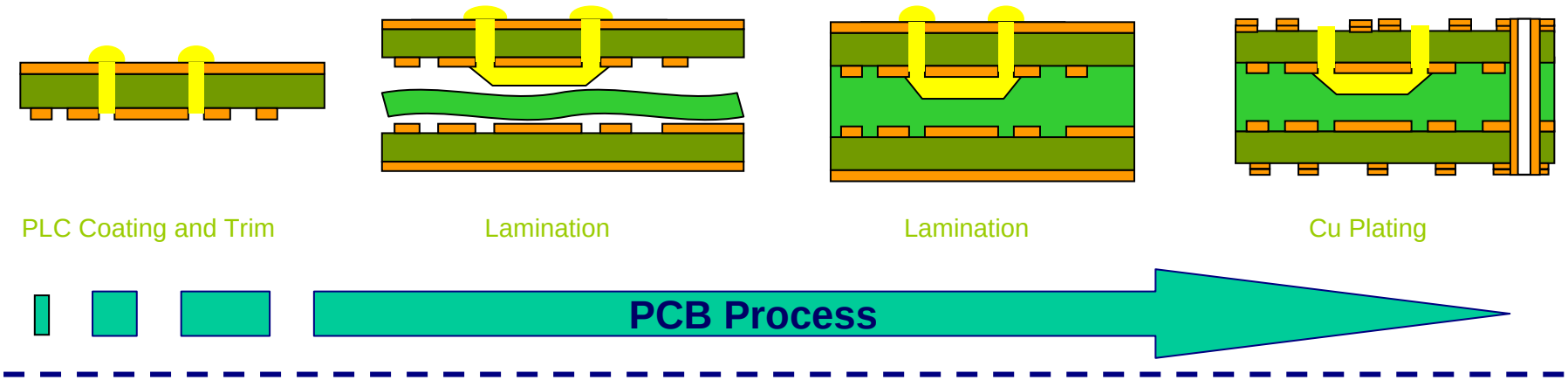
Waveguide Embedded OECB

- **Resistance to high temperature process: >180℃**



- **Optical Loss：<0.4dB/cm**

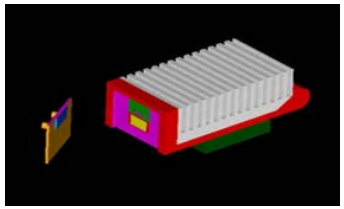




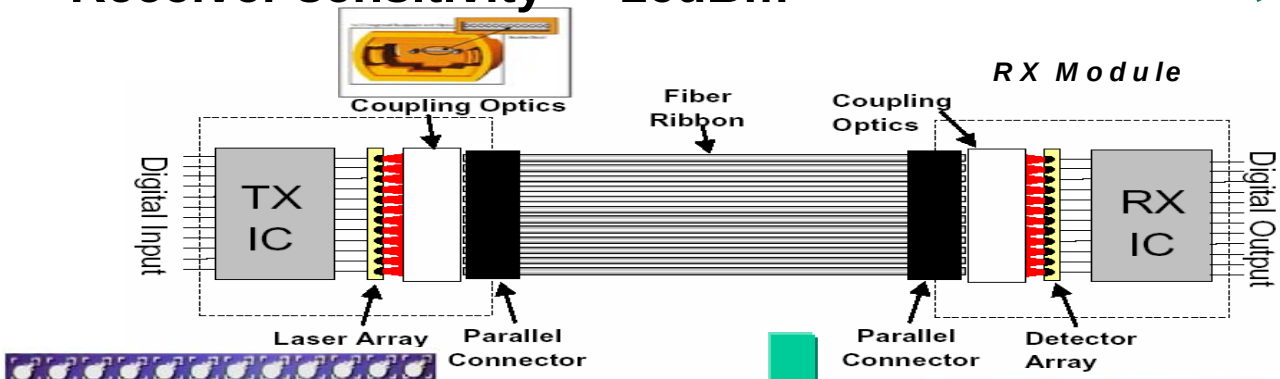
12 Channels Array Modules (Rack to Rack)

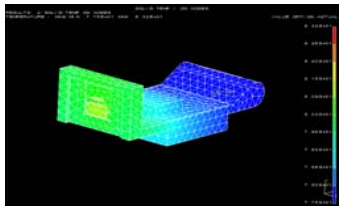
Features

- Conforms to the SNAP 12 MSA
- 12 Independent transmitter/Receiver channels
- Data rate up to 2.7Gbps per channel
- Whole flexible circuit board design
- Injection molding types lens cap
- Receiver sensitivity < -16dBm



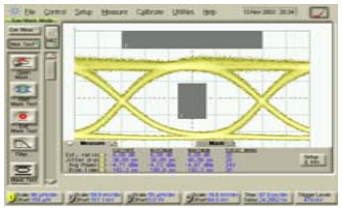
Array aspherical lens design





Thermal analysis

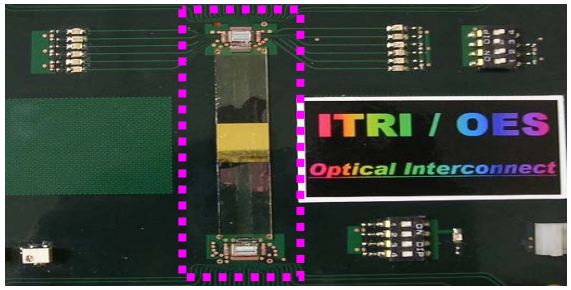
Injection molding lens cap

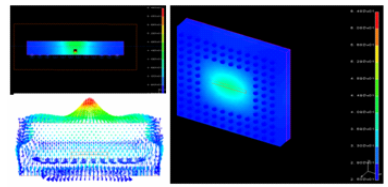


Eye diagram of array transmitter

12channels array module

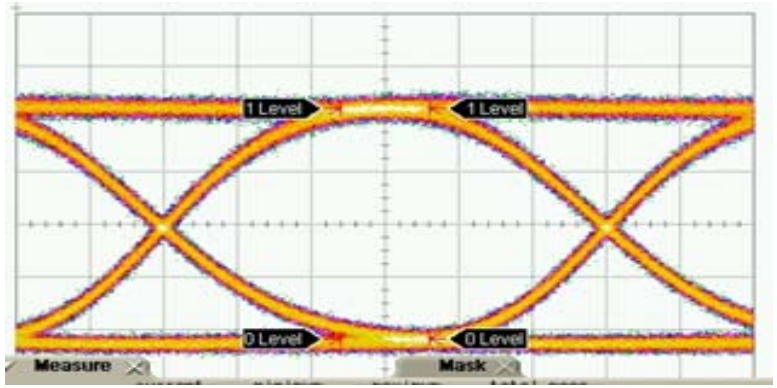
12 x 2.5Gb/s Chip to Chip on Glass Substrate



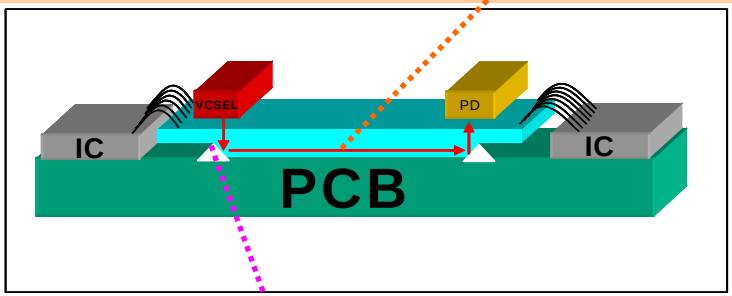


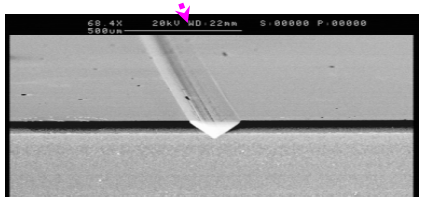
Optical Waveguide

12 x 2.5Gb/s Chip to Chip Optical Interconnection



Eye Diagram @ 2.5Gb/s through OECB



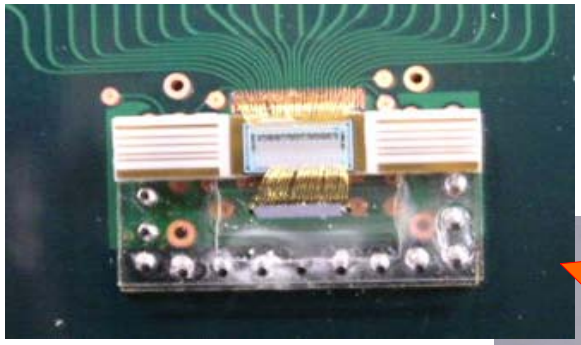


45 degree Optical Reflection Mirror

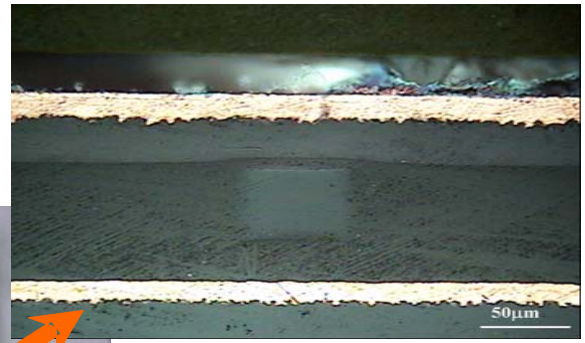
Parameter	Symbol	Min.	Typ.	Max.	Unit
Data Rate/ Channel			2.5		Gb/s
Wavelength	λ	830		860	nm
W.G. Channels			12		Number
W.G. Loss	Average		0.53		dB/cm
Extinction ratio	r_e	7			dB
Jitter				50	ps
Cross Talk			-	25	dB

C2C OI through Embedded OECB

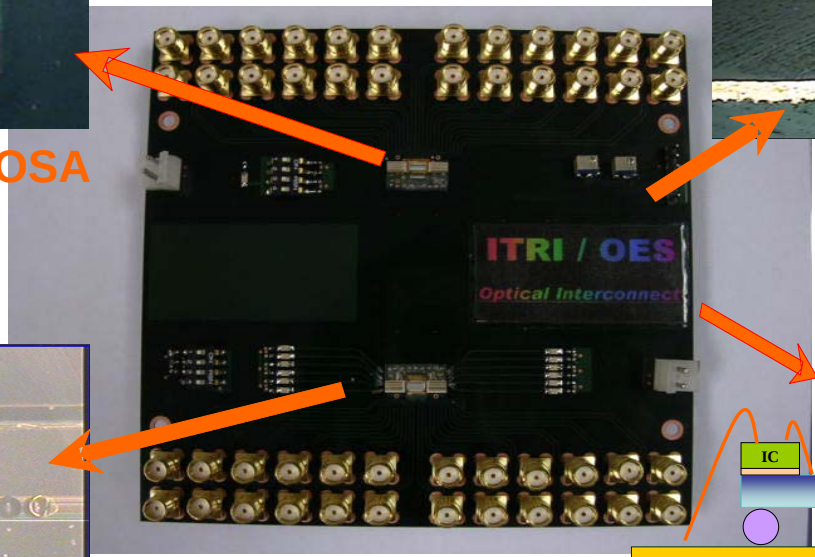
- The propagation loss of 6cm-long OECB is evaluated below 10dB.
- Eye diagram is also tested compliant with the requirement of OC-48 eye mask.



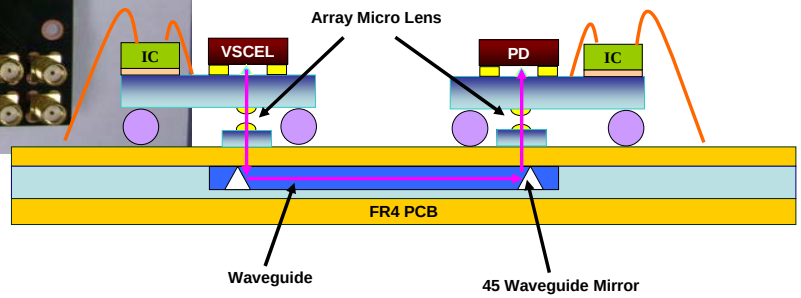
SMT 12 x 2.5G Array TOSA



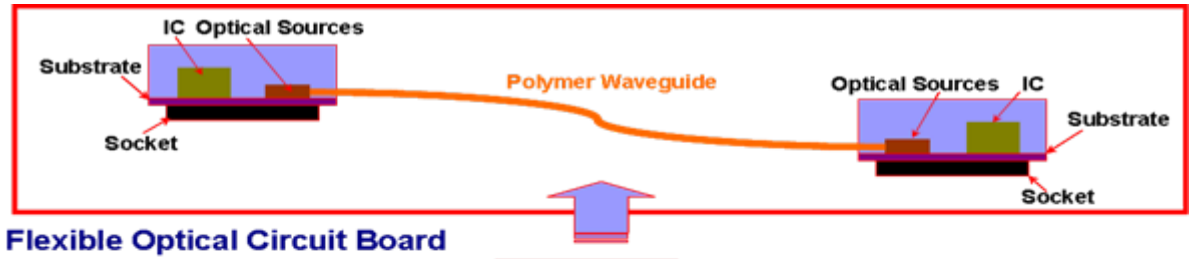
Embedded OECB



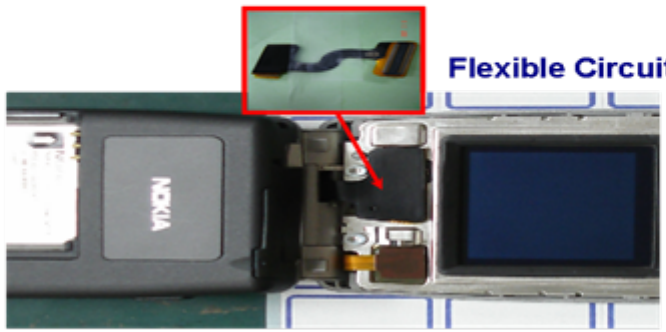
Array Lenses



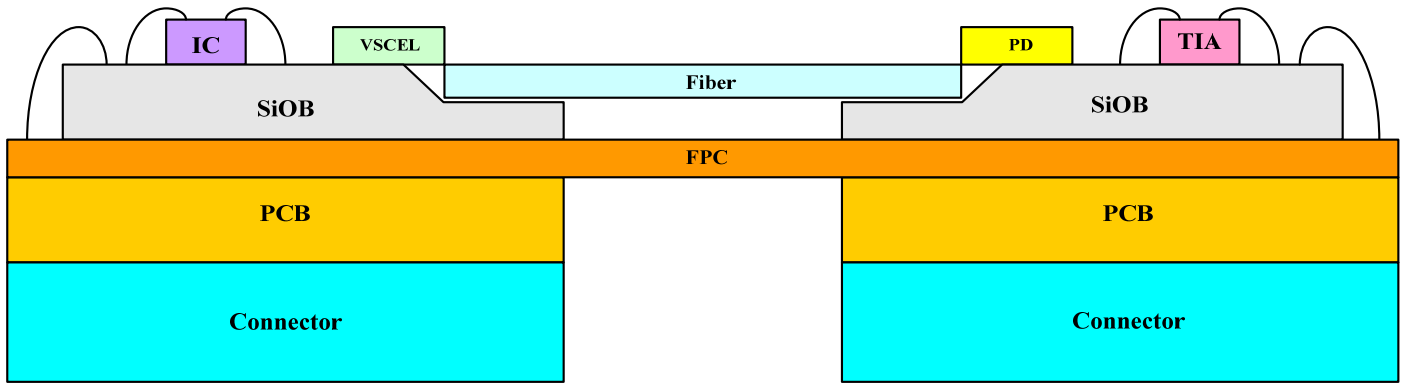
Flexible Optical Interconnects w/ SiOB



Flexible Optical Circuit Board



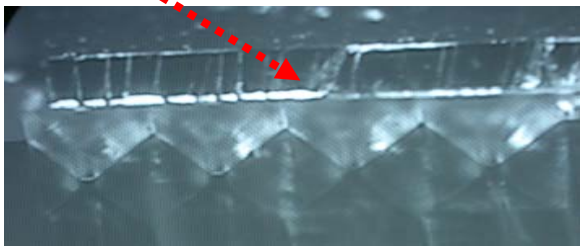
Inside of Cell Phone

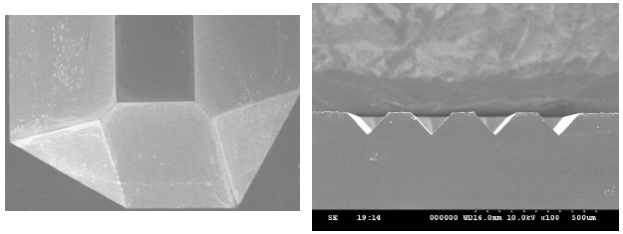


Structure for Mobile Phone Application

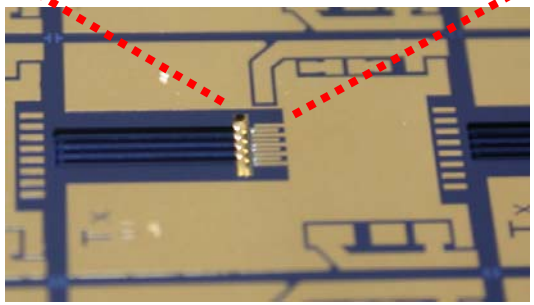
Flexible Optical Interconnects Performance

VCSEL Array

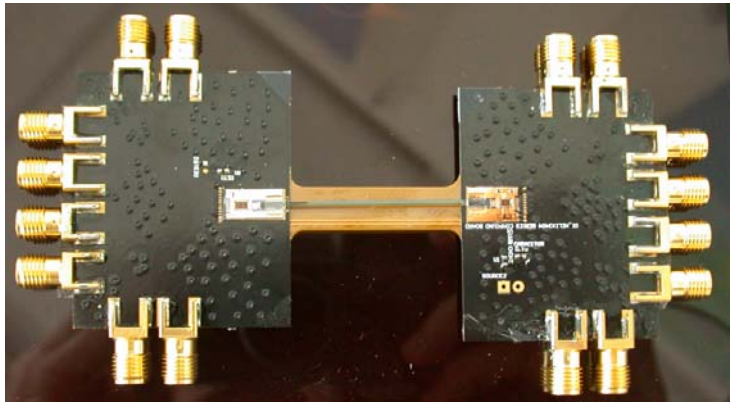




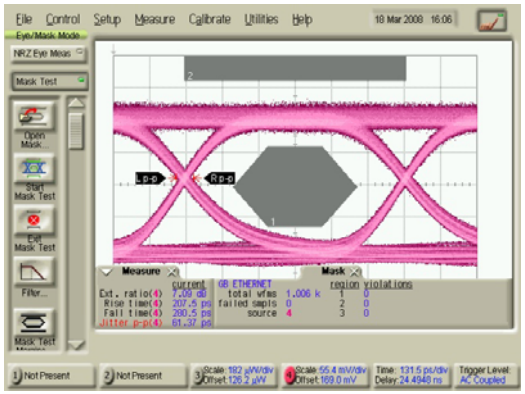
V-groove and 45 mirror

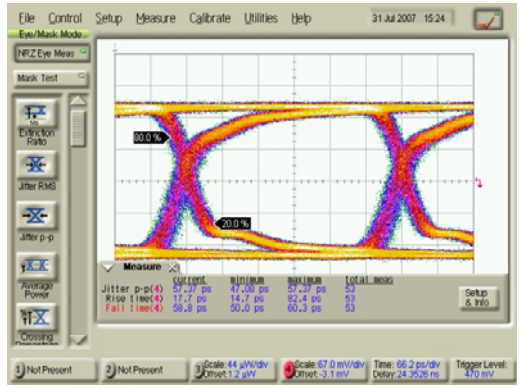


Passive Integration SiOB



4X2.5Gbps光連接模組雛型

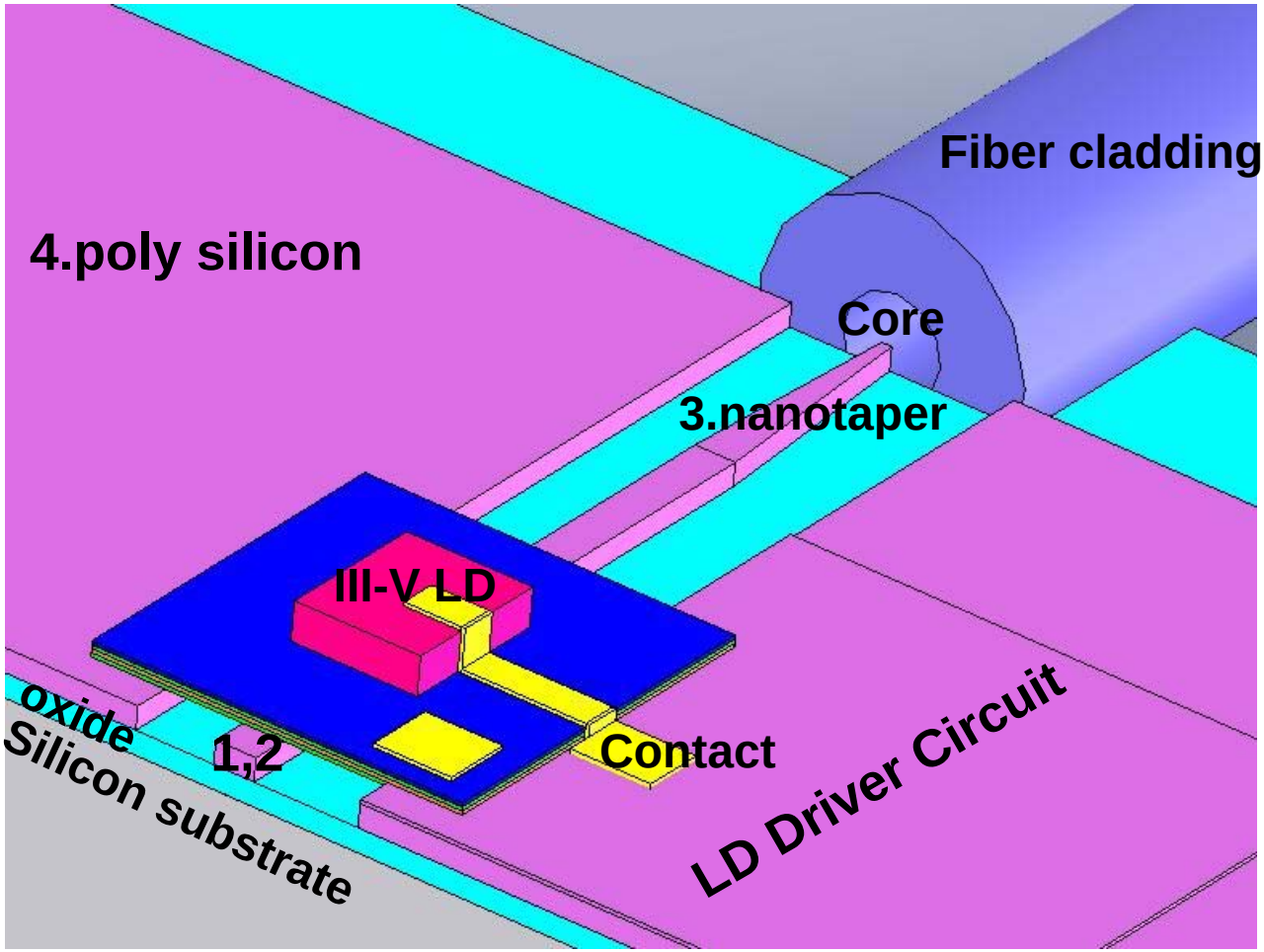




Tx and Rx Eye Diagram @ 2.5Gb/s

ITRI's Silicon Photonics Target

On-Chip Silicon Photonics



1. Hybrid evanescent coupling design.
2. Atomic bonding technology.
3. Fiber and nanowire coupling
4. Poly silicon annealing for low optical loss and high mobility.

Summarization

- **Optics must be one major substitution for traditional copper path at high frequency operation in the near future(2010~).**
- **Photonics Devices using silicon base material and standard , high volume silicon manufacturing techniques that will bring volume economics to optical interconnects.**
- **Flexible opt-electronics circuit boards have the advantages of high speed, immune to EMI and flexibility for assembly, it will be a potential innovation technique for future small-sized portable consumer products.**
- **Some prototypes of flexible OECBs have been demonstrated and deployed for consumer electronics such as mobile phone in Japan and Korea, but the power consumption of optical devices and O/E IC, cost are still important issues for implementation**