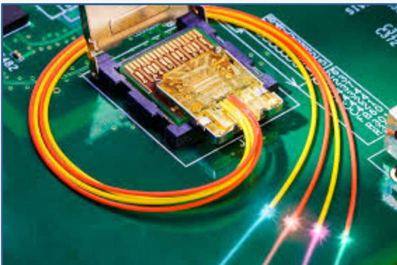
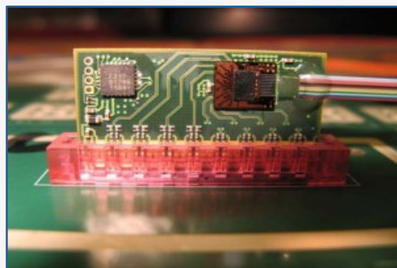
INTERCONNECT ROADMAP Nov 10, 2015

Interconnect Roadmap Submitted 10/1/15

36 Page Roadmap Dialog, Key Attributes by Product Area, Roadblocks, Paradigms, etc.

- **Roadmap Perspective – Global Supply Chain w/*US Mfg. of SiPh Systems, and US Companies* - In line with AIM Objectives**
- **Scope: Fiber Optic Connectors, Cable Assemblies, Active Interconnects, Organic PCBs**
- **No Show-Stoppers - New Connector Designs, and OPCBs are needed and doable. Cost will come down with HVM**





Level 0: On-Chip Cu/Glass Interconnects

Level 1: Chip-to-Package **Semiconducto**

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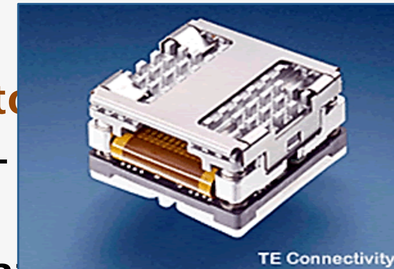

Level 2: Package-to-Board **Connectorization**

Level 3: Board Level Interconnects & Substrates

Level 4: Board-to-Board Interconnects

Level 5: Chassis-to-Chassis Cabling

Level 6: IO Ports (Active-Passive) e.g. LC Connector

Level X: Inter-System Cabling to 1km e.g. QSFP+

Future: Levels of Packaging will be Compressed into *Highly Integrated Photonic Sub-Systems* to Achieve THz SiPh System Performance at Minimum Cost-Reduction

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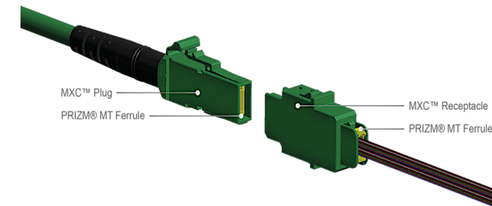
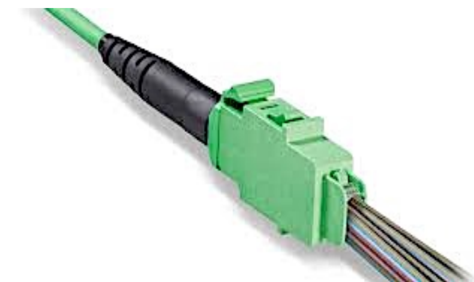
Driving Photonics Manufacturing

Table 1.2 Technology Roadmap: MXC
Single Mode Fiber Optic Connector PSMC Consortium 2000-2025

Roadmap Document: photonicsmanufacturing.org

Apps	Parameter	Metric	<2014	2015	2018	2025	Roadblocks	Comment
40-100G LAN	Package	Type	Multi-Fiber Cable Connector - Rect. Plug – Rx/Tx RJ45-type Latching Interface Plastic Housing					Ind. Standard
	Configuration	Type	Cable Assy, Plug, Receptacle, QSFP-MPO Fan-Out Cable					
Server	Multi-Fiber	Fiber Type	-	MM (SM)	SM	SM	None	Disaggregated Rack Servers 1.6-6.4Tb/ Cable
Storage	Insertion Loss	dB	1.2 – 1.5					
Switch	Max Fibers	Number	-	12	12-64	12-64		
	Cables	Mm OD	-	2.00 – 5.50				
Router	Compatibility	Types	-	MPO/MTP QSFP LC				
Data Center	Housing	Type	Engineered Polymer					Mat'ls Evolution
	Ferrule	Type	MT Expanded Beam					Japan - US
Other	Attenuation	dB	-	1.2-1.5				
	OPCB App	Y/N	Y – Module, Transceiver, IO, Fly-Over				Not Embedded	OPCB Devel.
	Speed/ channel	Gbps	-	40	100	100+/Fiber	None	Fiber-Dependent
	Alt. Technology	Type	MPO, QSFP, LC			New MXC	-	Beyond Cu
	Tech. Issues	Type	None				None	SM Field Assy.
	Supply Chain	Type	NA, Japan, TW			NA	Global	Need NA Infra.
	Encroachment	Type	10G Cu	25G Cu	40G Cu	-	-	SiPh Integration
	Cost	$/Fiber Interconnect	1.00	0.75 (10K)	0.50 (100K)	0.25 Millions	Fiber Installed costs > 40Gb inherently lower	Volume Dependent & Speculative
	Mfg. Process	Type	Insert Molding				None	None
	Showstoppers	Type	None				None	





Interconnect TWG

Electronic Connectors & Fiber Optic Technology:

- 30 Years of FO Development: Mature Technology with Room to Improve: SM Designs, Active Circuitry, Chip-Level Interconnect.
- Significant Globalization: Japan, EU, Taiwan, China
- New Challenge: *In-System* Packaging vs. Traditional Telecom/Outside Plant
- Cost Reduction will be an Issue: Needs HVM for a 2:1 Improvement

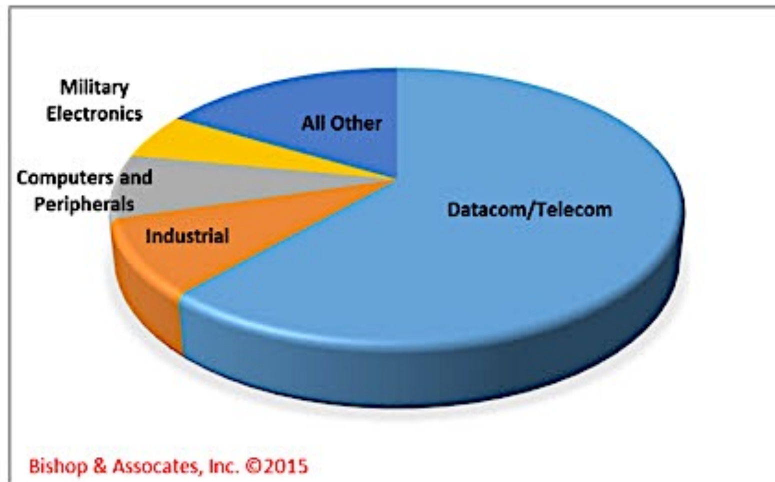
Organic Printed Circuits:

- Very Mature Technology, with Massive Offshore Mfg. Footprint to Lower Costs, Less Environmental Restrictions, Co-Locate with HVM of Electronic Systems
- Technology Breakthroughs in Photonics may come from outside the traditional PCB industry (Semiconductors, Academia)

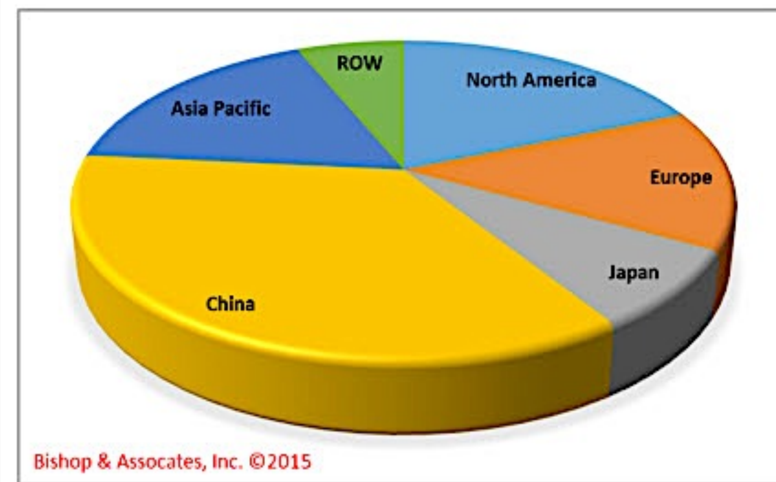
$125B Combined Connector and PCB Industries

- **Both Technologies are *Global* with HVM/LC in China & Asia-Pacific**
- **Both are Technically Mature with well over 500-combined Suppliers Worldwide.**
- **Connectors are 95% Cu-Alloy Based with a Myriad of Products and Applications. PCBs are 100% Cu and 100% Designed for Each OEM Application. i.e. Fiber Optics = 0-5% of Total Market.**
- **Circuit Speed to 40Gbps is Achievable at the Board Level with Cu.**
- **New Market for SiPh Systems is Emerging - The Number of SiPh-Capable Connector Companies are Limited but Adequate. No so in PCBs where no OPCB capability Currently Exists as a Production Capability**

FO Connector Markets



"FO Connector Revenues by Market Sector"



"Where Connectors are installed into Equipment"

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Some Key Interconnect Players

Connectors/Cables

#2 **Amphenol** (US HQ & Mfg)
FCI (SG HQ - Acquired by Amphenol 2015)
#3 **Molex** (US HQ - Acquired by Koch Ind. 2014)
Samtec (US HQ - Committed to FR SiPh Consortium)
#1 **TE Connectivity** (SUE HQ – US Mfg)
US Conec (US HQ - Corning Spin-off)
Largest Production Market: China

Substrates

#1 **TTM/Via Systems** (Merged 2015)
Other Domestic PCB Mfrs.
Sanmina-SCI & Other EMS
Japan/Taiwan World PCB Leaders
Possible: Polyimide/Silicone Flexible Circuitry and/or Printed Electronics
Silicon SiP/PoP/SoC (4 of the Top 100 PCB Makers are US-based)

Cable/Fiber Media

#1 **Corning Glass** (Optical Fiber)
DOW-Corning (Polymer Waveguides)
Connector & Cable Mfrs. (Cable Assemblies)

Interconnect Supply Chain

NA: OEMs - Contract Mfrs. - Connector Mfrs. - Materials & Equipment Suppliers
EU: Lots of RD&E - OEMs - Some Contract Mfg. - Some Connector Mfrs.
JP: RD&E - OEMs - Fiber Optic Connector Mfrs. - Ferrules - PCB Mfg.
AP/CN: HVM - CE - PC - Handset - Datacom – Standard FO Connector

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Overall Connector Mfg. & Supply Chain is Global 30% Domestic, 70% International

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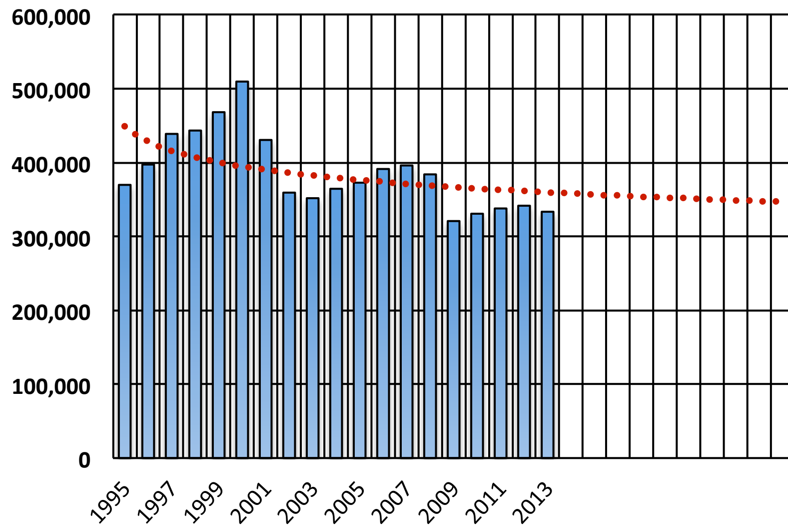
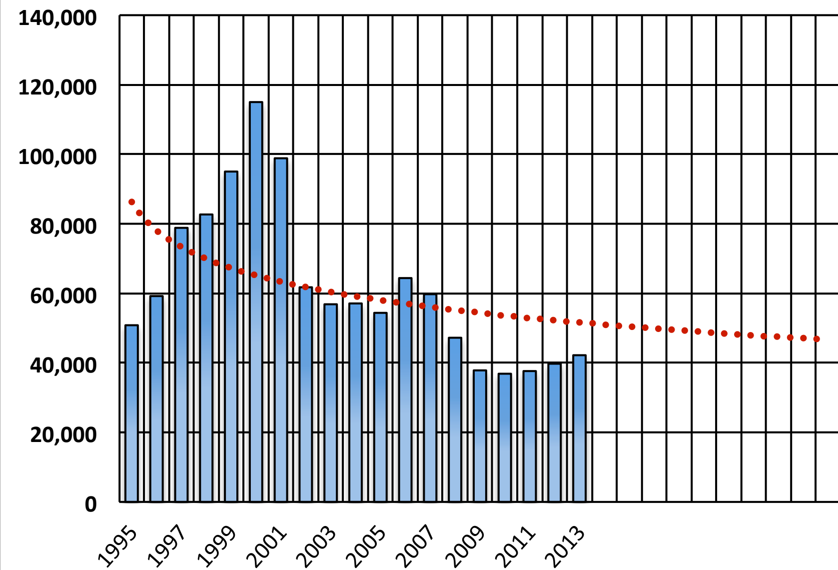
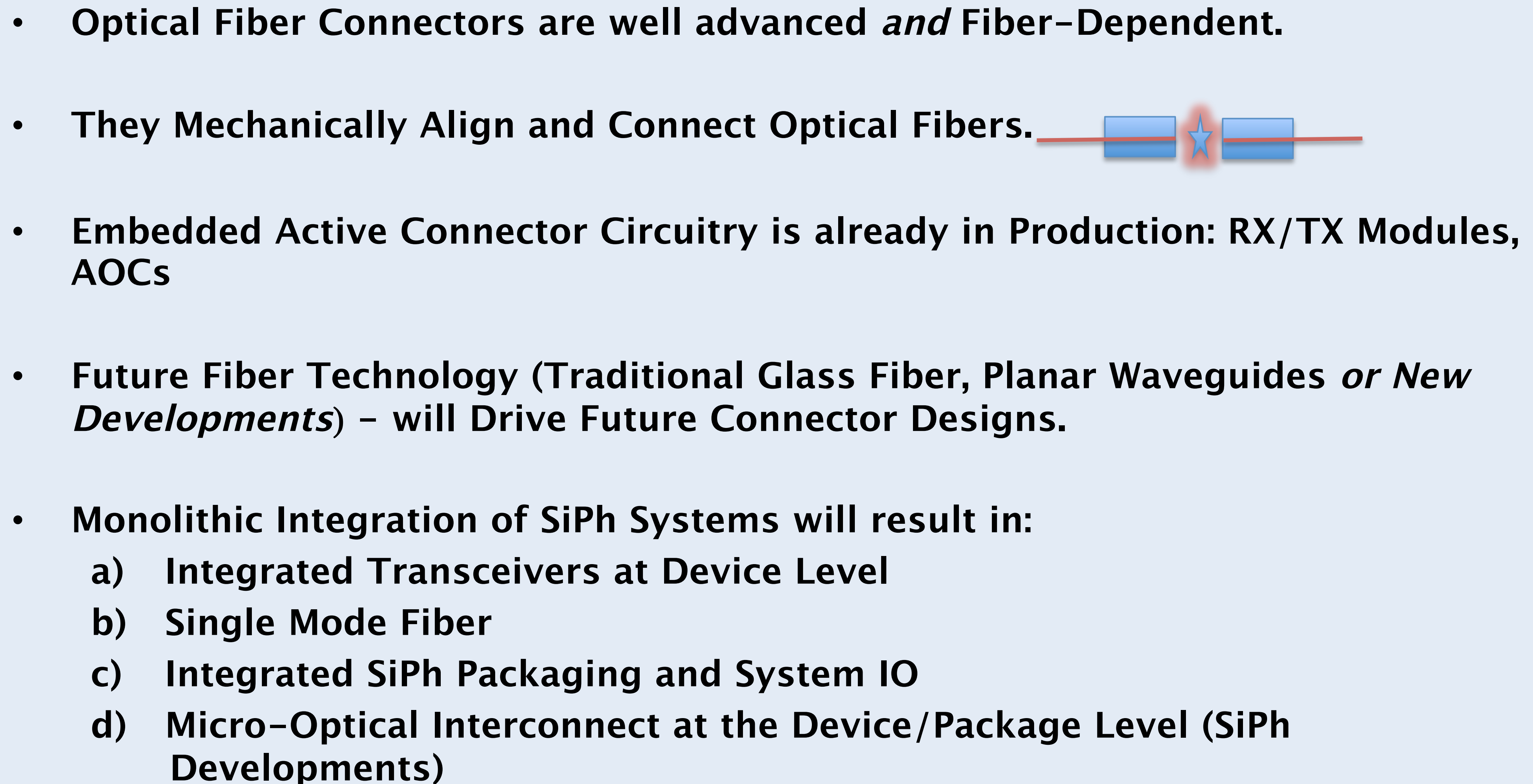
US Shipments of Electronic Products





Connector Technology



Interconnect Technology: Conclusions

- **Future HVM Mfg of SiPh Interconnect Products will Depend upon *OEM Commitments* and to a large degree, *Industry Standardization*.**
- **There are *no known Roadblocks* to Connecting Optical Fibers.**
- **Development work is underway on Chip/Package-Level Interconnects, Sockets and Interposers at the Semiconductor, Packaging & Connector Industry Levels – in their respective roles.**
- **Fiber Optic Connector Technology, both MM and SM can meet Level 2 through 6 Challenges that will arise in the SiPh Application Area.**
- **The PCB Industry, with one or two possible Domestic Exceptions, *is not ready* to offer Organic PCBs with Embedded Optical Waveguides. However, the Technology has been Demonstrated (DOW-Corning) and Above-Board Cabling is Available Now.**

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Interconnect Supply Chain

From a North American Perspective….

Existing Connector and Printed Circuit Board Industries are now at least 70% International and 100% Dependent on Globalized OEM Markets.

Design & Manufacturing Locations are and will be in NA, EU, JP, AP and CN….

The Goal….

Vibrant North American Si-Photonics Device and System-Level Manufacturing Industry for Computers and Datacom Products - *Including* the Now Pervasive Practice of *Outsourcing* System Assembly to EMS Specialists.

….Will Require a Supply Chain of Best-in-Class *Global* Electronic Component Suppliers and Technologies ….

Hard
Challenging

Can Do
Doing Now

Applications: Data Centers, HPCC, Future Servers

- Photonic Chip Waveguide to Optical Fiber Output
- Chip Package to Optical Interposer or RX/TX Module
- Optical Interposer to PCB Substrate w Embedded Fiber
- Discrete/Hybrid VCSEL Transceiver Module
- Embedded Waveguides
- PCB ‘Optical Micro-Via’ to SMT FO Connector
- MM/SM Fiber Optic Connectors w/Fly-Over In-System Cabling
- MM/SM FO Board-to-Board and Backplane Connectors
- Intra-System Cabling including AOCs/Rack-to-Rack
- Inter-System/LAN Cabling to 1Km (MM) and Beyond (SM)

Google Data Center

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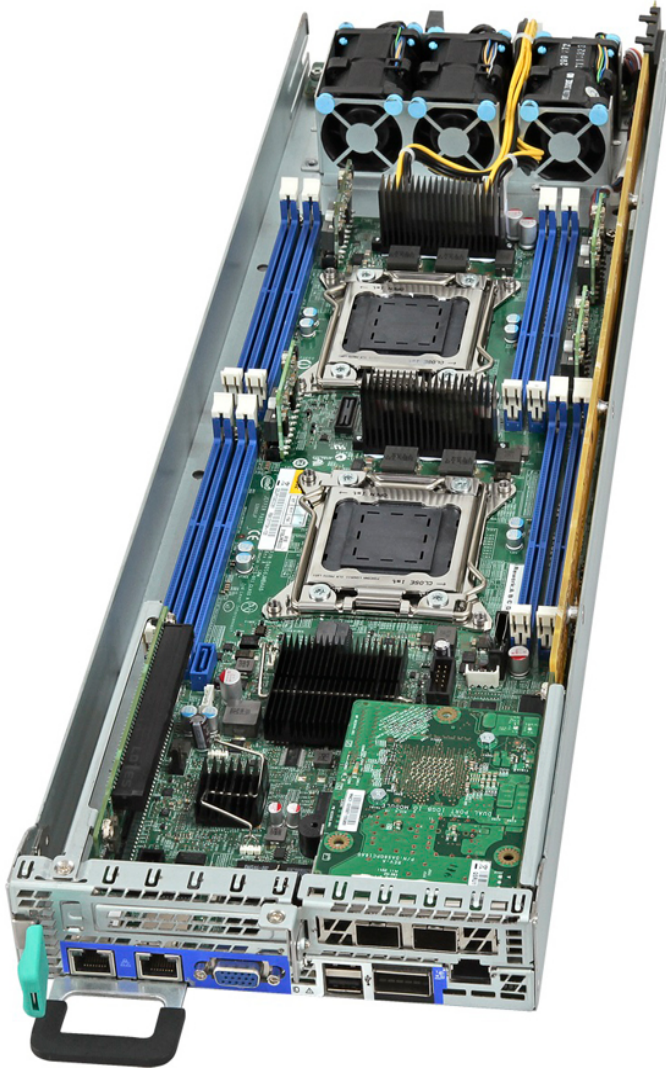
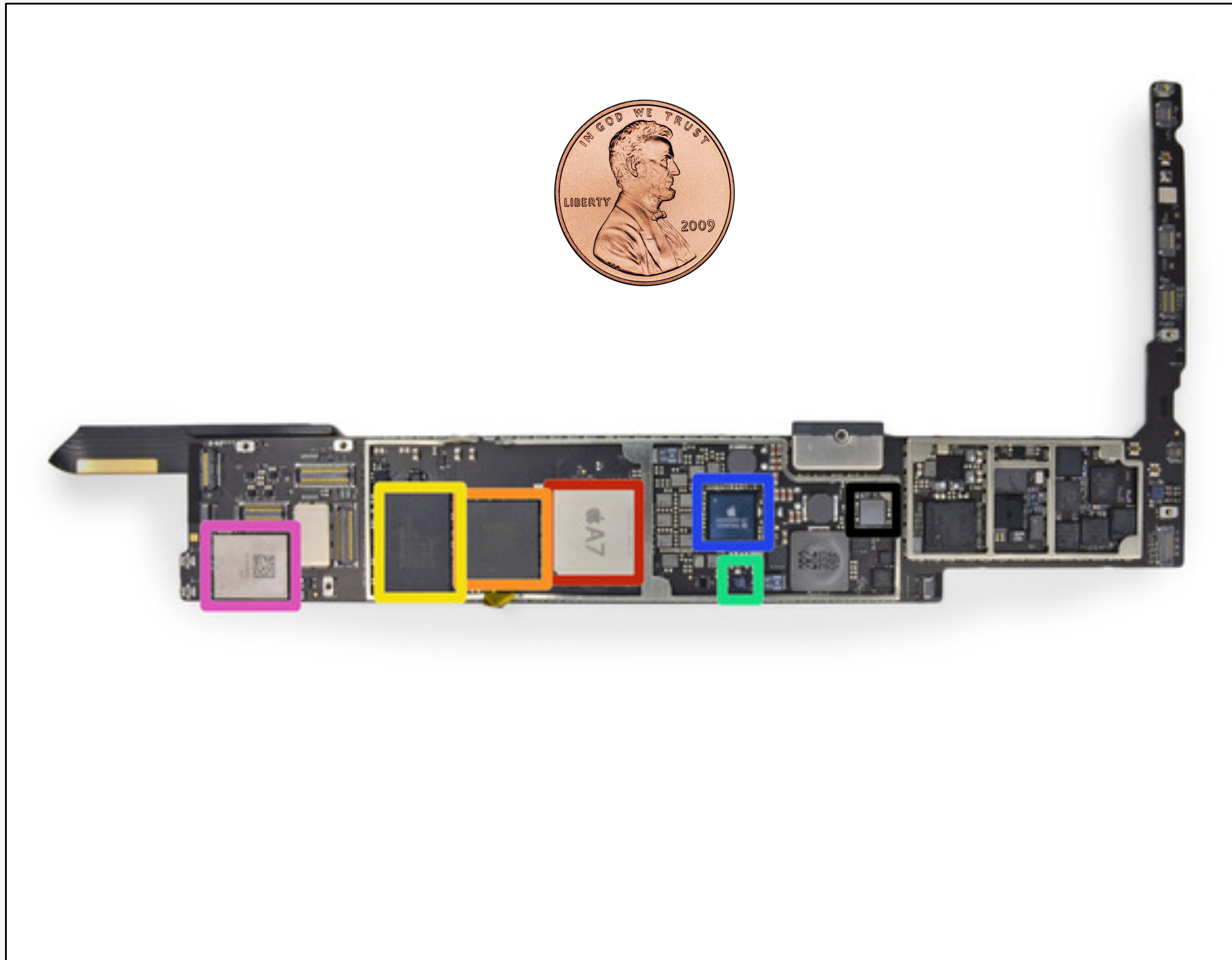
Intel Server MB

Intel Workstation MB

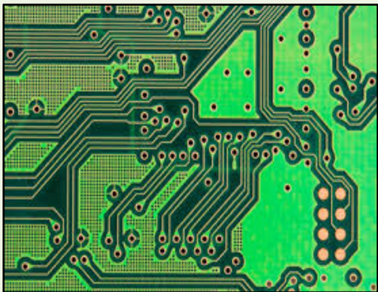


IPAD Air MB

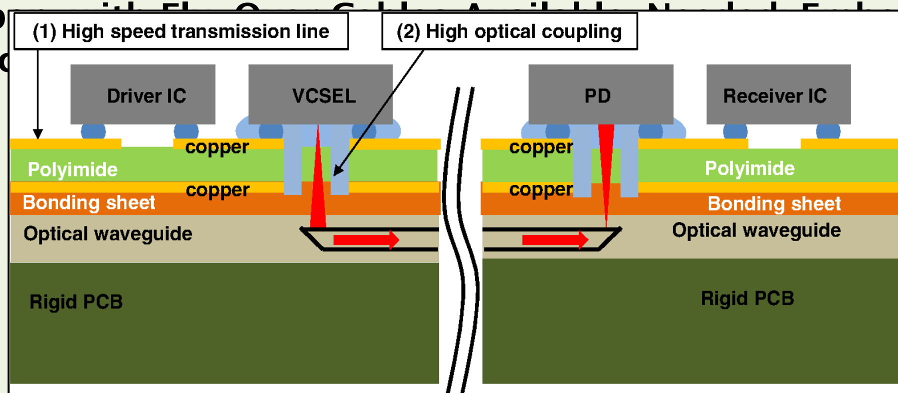


Cu vs FO Performance

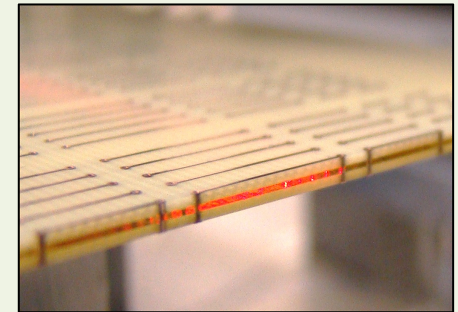
- Copper Circuitry is now Capable of 40G in the Box *and Cu Circuitry has surprised with USB and Thunderbolt @ 12Gbps and HP Backplane Connectors @ 25Gbps.*
- But…FO Connectors are essentially Speed-Independent.
- And…Fiber Optic Circuit Architecture is 'Different' than Cu: Essentially a Point-to-Point Interconnect vs 3D Cu Circuitry.
- FO Provides Lower Power, Fewer Rack-to-Rack Cables and Potentially Lower Overall System Cost.
- Challenge: Tb Speeds by 2020s, Pb 2030s. Parallel Optical Interconnects will be Necessary: 4 – 8 – 16 – 32 and doable now.
- Free-Space Optical Interconnect has Potential in future 'Sealed' Electronics.
- As will Future Developments in Waveguide Technology.
- OPCB Question is still op … lded Waveguides in Rigid and Flexible Circuitry + Surfac



Conventional Cu Laminate Organic PCB



SPIE Optical Engineering Paper Feb 2015



Fraunhofer IZM EO PCB Concept

Not Shown: DOW Corning Silicone PWG Developments, IBM Zurich Research, TTM Technologies OPCB Concept

Challenges

- There are a *Handful* of Connector and PCB Companies in EO Technology Sphere because it is a specialty technology needing years of experience to do more than make a connector or cable.
- There are *Supply Chain Issues* for an All-Domestic Mfg. Infrastructure.
- Industry Needs *Concrete System Design and OEM Commitments* to Develop and Tool New FO Products for HVM. This can be Accomplished '*One-On-One*', Through *Consortia* or Via *Industry Standards Groups*
- Applications *Closest to the Chip* are the most challenging unless Integrated into the System Package.
- There are Currently *No Embedded EOPCBs* – or *EOPCB SMT FO Connectors.*
- *Cost Targets* will *only* be achieved with OEM Commitments for HVM (10^{5-6}).
- *Disruptive Developments will occur* in this Program as SiPh Technology Progresses.

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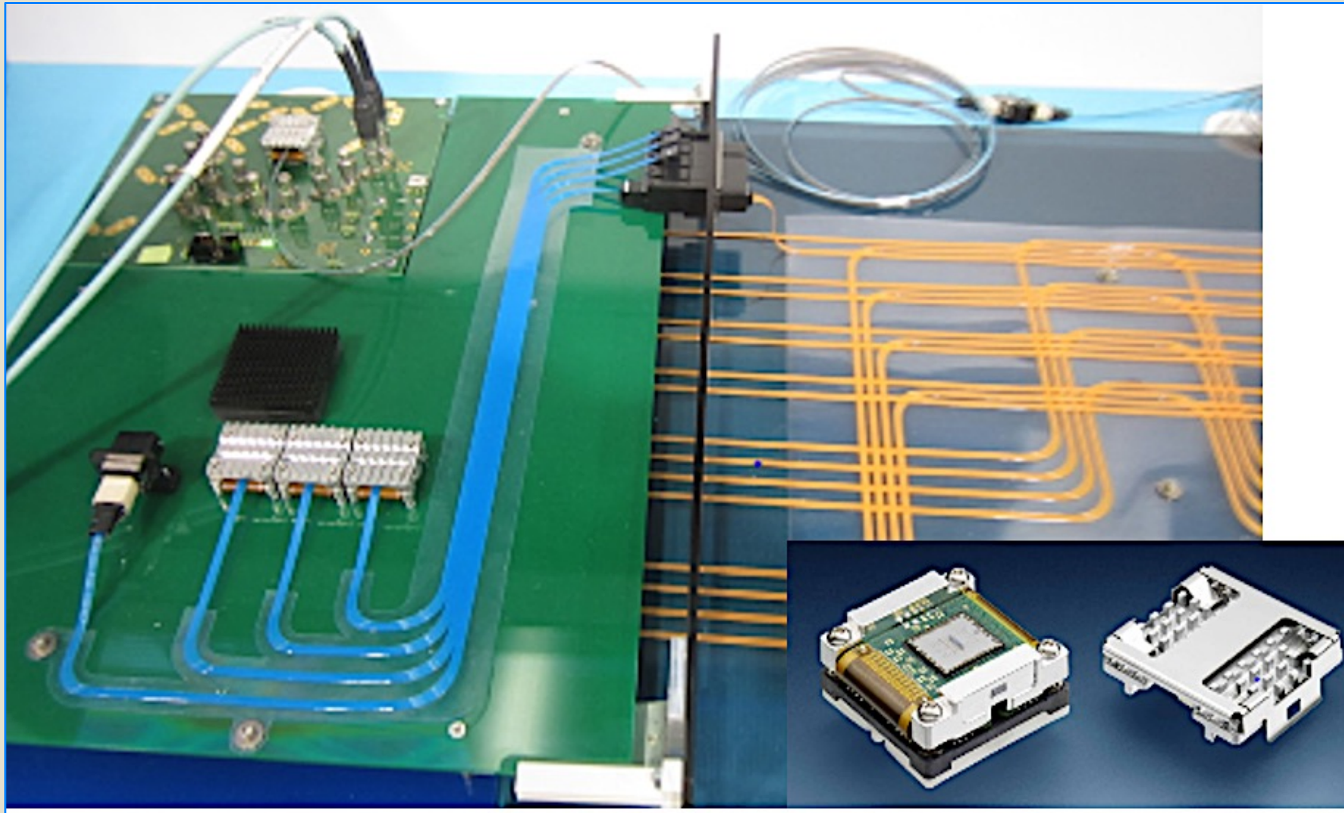
Roadmap is a Living Document

Interconnect Roadmap Document *IS For Comment*…Photonicsmanufacturing.org….Below TE Connectivity CoolBit Optical Engine 4x100gbps

One Page White Papers are Encouraged by Industry Personnel



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