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 Semiconductors

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

<table>
<thead>
<tr>
<th>Apps</th>
<th>Parameter</th>
<th>Metric</th>
<th>&lt;2014</th>
<th>2015</th>
<th>2018</th>
<th>2025</th>
<th>Roadblocks</th>
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<td>Configuratio</td>
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<td>Multi-Fiber</td>
<td>In T  ection Loss d B</td>
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<td></td>
<td></td>
<td></td>
<td>2.00 – 5.50</td>
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<td>Horseback</td>
<td>Max Fibers Number</td>
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<td>Mat’ls Evolution</td>
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<td><strong>Other</strong></td>
<td>Compatibility</td>
<td>Types</td>
<td>MPO/MTP QSFP LC</td>
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<td></td>
<td></td>
<td></td>
<td>J a p a n - U S</td>
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<td></td>
<td>Housing</td>
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<td>10G Cu</td>
<td>25G Cu</td>
<td>40G Cu</td>
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<td>-</td>
<td>-</td>
<td>Fiber - Dependent</td>
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<td>Cost $/Fiber Interconnect</td>
<td>1.00</td>
<td>0.75 (10K)</td>
<td>0.50 (100K)</td>
<td>0.25</td>
<td>Millions</td>
<td>Fiber Installed costs &gt; 40Gb inherently lower</td>
<td>Volume Dependent</td>
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Roadmap Document: [photonicsmanufacturing.org](http://photonicsmanufacturing.org)
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)
• 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"
## Some Key Interconnect Players

<table>
<thead>
<tr>
<th>Connectors/Cables</th>
<th>Substrates</th>
<th>Cable/Fiber Media</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>#2 Amphenol</strong> (US HQ &amp; Mfg)</td>
<td><strong>#1 TTM/Via Systems</strong> (Merged 2015)</td>
<td><strong>#1 Corning Glass</strong> (Optical Fiber)</td>
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<tr>
<td><strong>FCI</strong> (SG HQ - Acquired by Amphenol 2015)</td>
<td><strong>Other Domestic PCB Mfrs.</strong></td>
<td><strong>DOW-Corning</strong> (Polymer Waveguides)</td>
</tr>
<tr>
<td><strong>#3 Molex</strong> (US HQ - Acquired by Koch Ind. 2014)</td>
<td><strong>Sanmina-SCI &amp; Other EMS</strong></td>
<td><strong>Connector &amp; Cable Mfrs.</strong> (Cable Assemblies)</td>
</tr>
<tr>
<td><strong>Samtec</strong> (US HQ - Committed to FR SiPh Consortium)</td>
<td><strong>Japan/Taiwan World PCB Leaders</strong></td>
<td></td>
</tr>
<tr>
<td><strong>#1 TE Connectivity</strong> (SUE HQ – US Mfg)</td>
<td><strong>Possible: Polyimide/Silicone Flexible Circuitry and/or</strong></td>
<td></td>
</tr>
<tr>
<td><strong>US Conce</strong> (US HQ - Corning Spin-off)</td>
<td><strong>Printed Electronics</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Largest Production Market:</strong> China</td>
<td><strong>Silicon SiP/PoP/SoC</strong> (4 of the Top 100 PCB Makers are US-based)</td>
<td></td>
</tr>
</tbody>
</table>

### Interconnect Supply Chain

- **NA:**
  - OEMs - Contract Mfrs. - Connector Mfrs. - Materials & Equipment Suppliers

- **EU:**

- **JP:**
  - RD&E - OEMs - Fiber Optic Connector Mfrs. - Ferrules

- **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*
### 1.9 US Shipments Computers & Electronic Products

**1995-2025 Trend**

### 1.10 US Shipments Communication Equip - Non-Defense

**1995-2025 Trend**

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**US Shipments of Electronic Products**

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### PSMC

Driving Photonics Manufacturing
Connector Technology

- Optical Fiber Connectors are well advanced *and* Fiber-Dependent.

- They Mechanically Align and Connect Optical Fibers.

- Embedded Active Connector Circuitry is already in Production: RX/TX Modules, AOCs

- Future Fiber Technology (Traditional Glass Fiber, Planar Waveguides *or New Developments*) – will Drive Future Connector Designs.

- Monolithic Integration of SiPh Systems will result in:
  a) Integrated Transceivers at Device Level
  b) Single Mode Fiber
  c) Integrated SiPh Packaging and System IO
  d) Micro-Optical Interconnect at the Device/Package Level (SiPh Developments)
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.
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....


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


- 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 open, with Fly-Over Cables Available. Needed: Embedded Waveguides in Rigid and Flexible Circuitry + Surface FO Connectors.

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.
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*
CLICK HERE TO SEE THE WEBINAR RECORDING