Optical Interconnects:
Trend and Applications

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EOL, ITRI

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OUTLINE

✓ Background and Motivation
✓ Trends of Optical Interconnects Technology and Application
✓ OI Research In EOL/ITRI
✓ Summarization
-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
- Thermal problem limits CPU clock rate, and performance.
- Multi-core solution results in larger RC delay.
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

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

## 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

Source from IBM, 2005
Elements of Optical Interconnects

- **Electronics Chips**
  - Laser, PD
  - Driver, TIA, Post amplifier

- **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

<table>
<thead>
<tr>
<th>Solution</th>
<th>Intel</th>
<th>IBM</th>
<th>EU-IO Project</th>
<th>NEC</th>
<th>Korea ICU</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-SiOB(B2B)</td>
<td>-Si Module</td>
<td>-SiOB(B2B)</td>
<td>-SiModule</td>
<td>-SiOB(B2B)</td>
</tr>
<tr>
<td></td>
<td>-FCPGA(C2C)</td>
<td>-Rigid OECB</td>
<td>-FCPGA(C2C)</td>
<td>-FCPGA(C2C)</td>
<td>-FCPGA(C2C)</td>
</tr>
<tr>
<td></td>
<td>-Silicon laser</td>
<td></td>
<td>-Silicon laser</td>
<td></td>
<td>-Silicon laser</td>
</tr>
<tr>
<td></td>
<td>-MM Fiber Array</td>
<td></td>
<td>-MM Fiber Array</td>
<td></td>
<td>-MM Fiber Array</td>
</tr>
<tr>
<td>Application</td>
<td>Backplane, Sever, CPU</td>
<td>Backplane, Sever, Supercomputer</td>
<td>Backplane, Sever, Supercomputer</td>
<td>Backplane, Sever, Supercomputer</td>
<td>Backplane, Sever, Supercomputer</td>
</tr>
<tr>
<td>Application</td>
<td>Nokia</td>
<td>Samsung</td>
<td>Panasonic</td>
<td>Sumitomo Bakelite</td>
<td>OMRON</td>
</tr>
<tr>
<td>Solution</td>
<td>-Flexible OECB</td>
<td>-Flexible OECB</td>
<td>-Flexible OECB</td>
<td>-Flexible OECB</td>
<td>-Flexible OCB</td>
</tr>
<tr>
<td>Application</td>
<td>Cell Phone</td>
<td>Cell phone</td>
<td>Cell Phone, Camera</td>
<td>Cell Phone</td>
<td>Cell Phone</td>
</tr>
</tbody>
</table>

Source from Panasonic and Omron

**Backplane Applications**

**Consumer Electronics**
# Copper FPC vs Flexible OECB

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

- **Medium**
  - Fiber (silica / polymer)
  - Waveguide (polymer)

- **Substrate (construction)**
  - Flexible substrate
    - Incl. sheet, FPC, without
  - Rigid substrate
    - Incl. board, PCB, without

<table>
<thead>
<tr>
<th></th>
<th>Rigid</th>
<th>Flexible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber</td>
<td><img src="rigid_fiber.png" alt="Image" /></td>
<td><img src="flexible_fiber.png" alt="Image" /></td>
</tr>
<tr>
<td>Waveguide</td>
<td><img src="rigid_waveguide.png" alt="Image" /></td>
<td><img src="flexible_waveguide.png" alt="Image" /></td>
</tr>
</tbody>
</table>
OE Module and OECB Optical Integration

Source from NTT, 2003

SMT Compatible Optical Interface

Source from UCSB, 2006

Optical Connector

Evanescent Coupling
Optical Backplane of Fiber Flexible OECB

Fiber flexible OCB (192ch)

Right angled connector

board side

backplane side

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**

![Diagram of measurement setup](image)

- Optical source
- Optical fibre
- Waveguide
- Optical power meter
- Coupling point

**Graph**

- Y-axis: Loss (dB)
- X-axis: Length (cm)
- Equation: \( y = 0.255x + 0.9467 \)

**Cut back Channel loss** ~< 0.3dB/cm
Waveguide Embedded OECB

- Resistance to high temperature process: >180°C
- 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
**12 x 2.5Gb/s Chip to Chip on Glass Substrate**

**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

**Eye Diagram @ 2.5Gb/s through OECB**

**45 degree Optical Reflection Mirror**
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.
Flexible Optical Interconnects w/ SiOB

Flexible Optical Circuit Board

Flexible 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 光連接模組組件型

Tx and Rx Eye Diagram @ 2.5Gb/s
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.
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.