Silicon Photonics in Mainstream Applications

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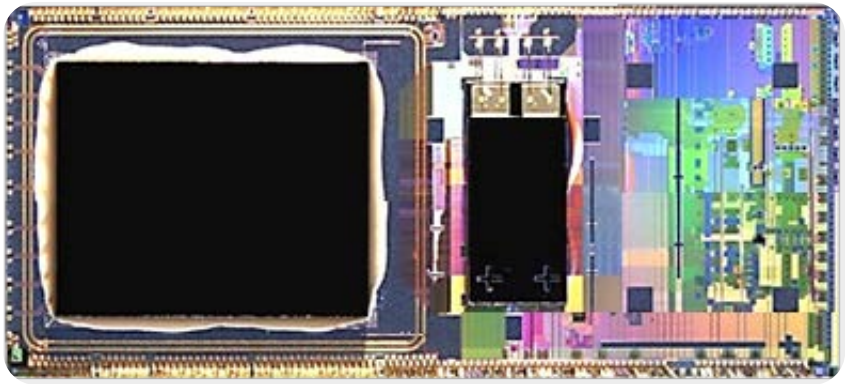
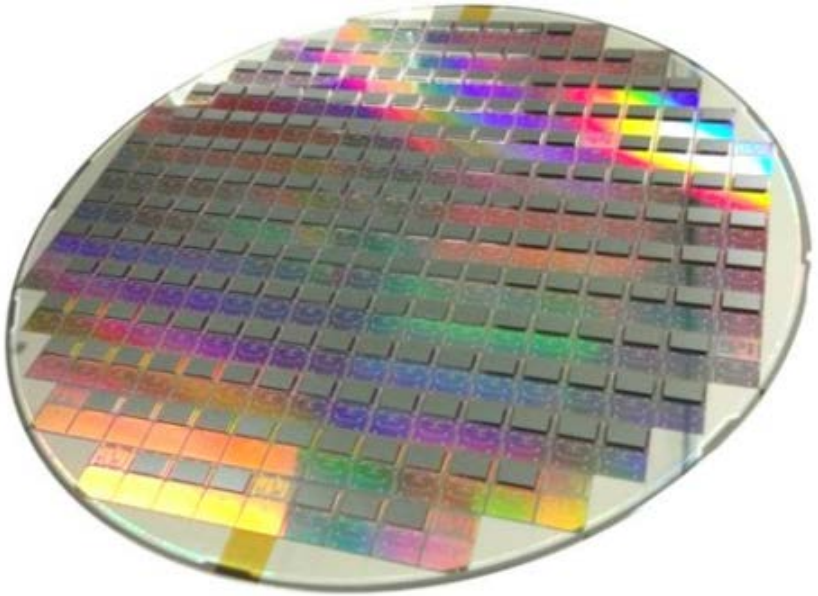
What is “Silicon Photonics”

- “Silicon Photonics” is used to describe many different technologies
- At it’s simplest form it is a photonics integrated circuit (PIC) that has some silicon in it
- Luxtera technologies focus on the manufacture of electro-optical integrated circuits in standard CMOS foundries



EX: 100G-PSM4 Silicon Photonics Chipset



What is a “Mainstream Application”

- “Mainstream Applications” are those with broad usage, and/or high volume
- Compared to “Niche Applications”, which tend to be very specific and low volume
- It is a relative measure
  - IE, volumes that might constitute mainstream for enterprise markets might be considered niche vs. consumer markets

What this means in optics

- Mainstream optical applications tend to be/have:
  - Higher volumes
  - Standard (or MSA) coverage
  - More barriers to entry
  - More commoditization (ie, multi-source)

- Niche Applications tend to be/have:
  - Lower volumes
  - Can be proprietary
  - Fewer barriers to entry
  - Less commoditization (can be single source)

Silicon Photonics in Mainstream Applications

Several factors have impacted the rate at which Silicon Photonics becomes mainstream:

1. Barriers to Entry
   - High volume customers like to buy multi-sourced components that meet an industry standard
   - Industry standards have typically been built around existing technologies, with little consideration upon emerging technologies

2. Design/Development cost
   - While per unit COGS is typically lower, technology development and solution design costs can be higher in silicon photonics designs than in conventional optics
   - In low volume markets this can burden the per unit cost.
   - The most successful markets are those where amortization of these costs will not significantly burden per unit COGS

Silicon Photonics in Mainstream Application

- The **ideal** market would have the following attributes:
  - It would be high volume (ie, 100kU-1MU per year)
    - Solution design costs do not factor into per unit costs
  - It would have few barriers to entry (ie, standards enabling SiP)
    - Multi-source to give end users confidence in deployment
  - It would allow for positive differentiation
    - Silicon photonics could be lower cost, higher performance than conventional technologies
  - It would fit into a broader product family/roadmap
    - Technology development costs can be leveraged across multiple generations

Silicon Photonics in Mainstream Applications

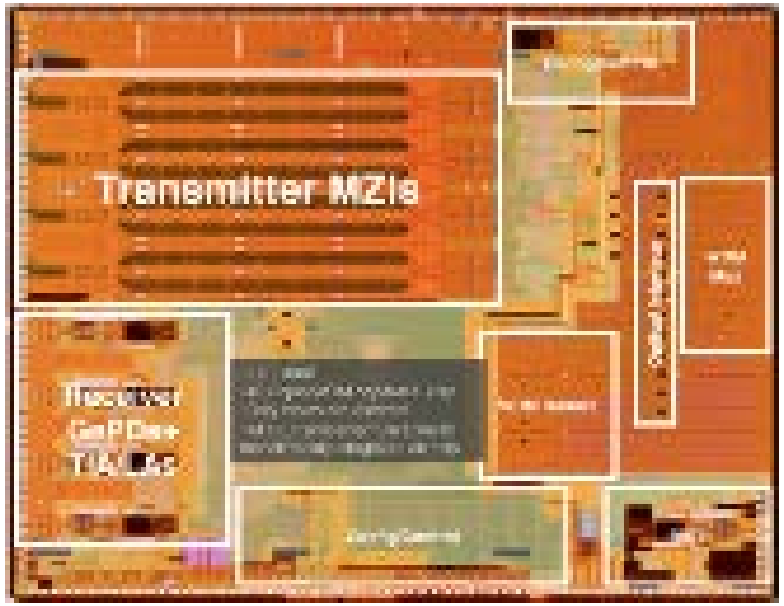
- The **non-ideal** market would have the following attributes:
  - It would be low volume
    - Solution design costs would factor heavily into per unit costs
  - It would be proprietary
    - Sole-source to end users
  - It would have little differentiation against conventional technologies
  - It would be a “one off” product
    - With unique technologies needed just to service one generation of product

How does one get to the “Mainstream Application”

- The most likely path to the “mainstream application” is to try everything else first…
- The first application (attempt) is likely to be something fairly complex
- The second attempt is likely to be something much simpler
- Can take until the third (or more) attempt until one hits their stride

First Application: An Example

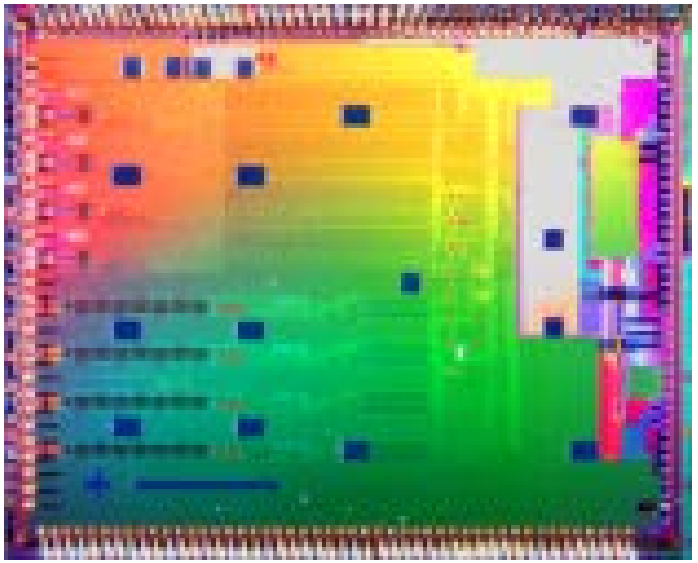
- Year: 2006
- Chipset: 4λx10 Gbps WDM transceiver
- Wavelength(s): 1550



- Strengths:
  - Complete integration of WDM MUX/DEMUX
  - Complete integration of all TX/RX electronics and photonics (except light source)
- Barriers to deployment:
  - Required a seperate light source per lane (same as discrete optics)
  - Proprietary solution (not multi-sourced)

Second Application: An Example

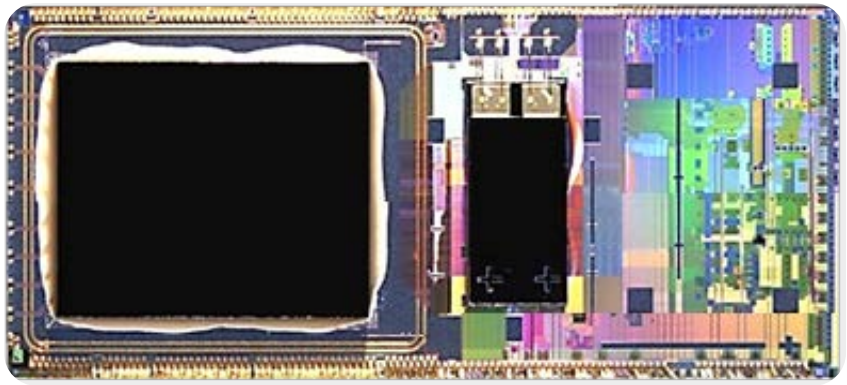
- Year: 2009
- Chipset: 4x10 Gbps “PSM4” transceiver (AOC chipset)
- Wavelength: 1490



- Strengths:
  - Single light source for all channels
  - Complete integration of all TX/RX electronics and photonics (except light source)
- Barriers to deployment:
  - Closed optical interface (due to proprietary wavelength)

Third Application: An Example

- Year: 2015
- Chipset: 100G-PSM4 transceiver chipset
- Wavelength: 1310



- Strengths:
  - Single light source for all channels
  - Complete integration of all TX/RX electronics and photonics (except light source)
  - MSA coverage of optical interface

Future Applications

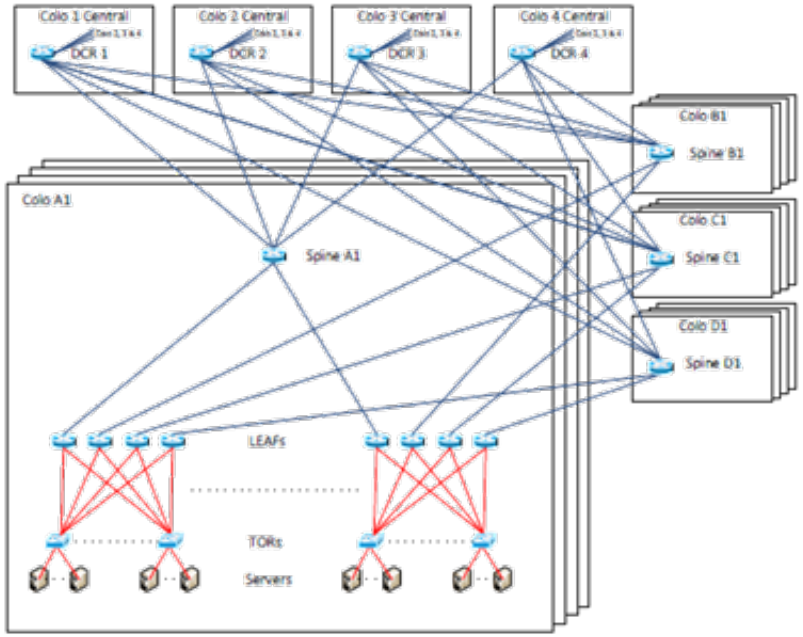
- The move to cloud computing is increasing the size of datacenters
  - From 300m max intra-DC reach to 500m-1000+m
  - Pushes the need for increasing use of SMF in the datacenter
    - Some DC using only SMF
- Cloud computing is pushing for increased interconnect speeds
  - Faster adoption than classical enterprise markets
  - Higher rates reducing the reach of both MMF and copper solutions

Future Application – Cloud DC

Global Networking Services

Representative Cloud Scale Data Center Design

Representative Data Center Campus Interconnections



Interconnections

- Multiple interconnection lengths are required
- There are multiple colo areas per data center so the total number of links will vary
- All link quantities are per colo area

A End	Z End	Link Quanity	Link Length	Type of interconnection
Server	TOR	10,000s	.5-3m	TwinAx
TOR	LEAF	1,000s	1-20m	AOC
LEAF	SPINE - local	100s	20-300m	SM fiber
LEAF	SPINE - inter building	1,000s	100-400m	SM fiber
SPINE	DCR	100s	100-1,000m	SM fiber
INTRA METRO		100s	1,000m+	SM fiber

Microsoft

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Future Applications – Cloud DC

- Three high volume reaches within the data center
  - Server to TOR (Intra-Rack): Sub 3m
  - TOR to Leaf (Intra-Row): 3-20m
  - Leaf to Spine (Intra-DC): 20m+ (up to 500-1000m)

- Within each reach the trend is toward a common interconnect type
  - Practical reach transitions occur at 3m and 20m
  - Below 3m almost exclusively copper (at present)
  - 3m-20m often AOC (limited need for patch panels)
  - Above 20m much conversion to SMF (MMF cannot service all reaches)

Future Applications - Cloud DC

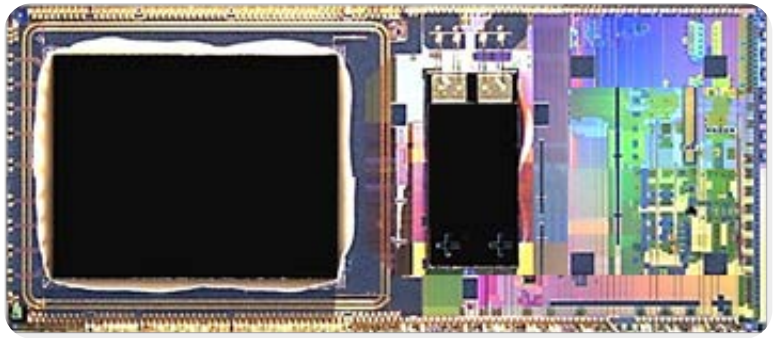
- Rate increases expected to further diminish the reach of copper and MMF interconnects
  - Server I/O rates increasing from 10G ->25G -> 50G ->100G
  - Switch I/O rates increasing from 40G -> 100G -> 400G
    - 200G as a switch I/O rate still unclear
- Eventually copper will no longer be able to service all intra-rack interconnects
  - Will that lead to mixed deployment of copper and optics within the rack…. or?
  - Will the DC shift to all optics
- What role will MMF play in the future of Cloud DC?
  - Currently deployments often restricted to AOC type “closed” optics
  - Will their be open optics within the row? If so will it also go SMF?
- Will DC architectures change when people are no longer trying to enable copper?
  - Consolidation onto a single interconnect type/standard may have certain advantages
  - Such solutions would need to be economically viable at short reach, and technically viable at long reaches

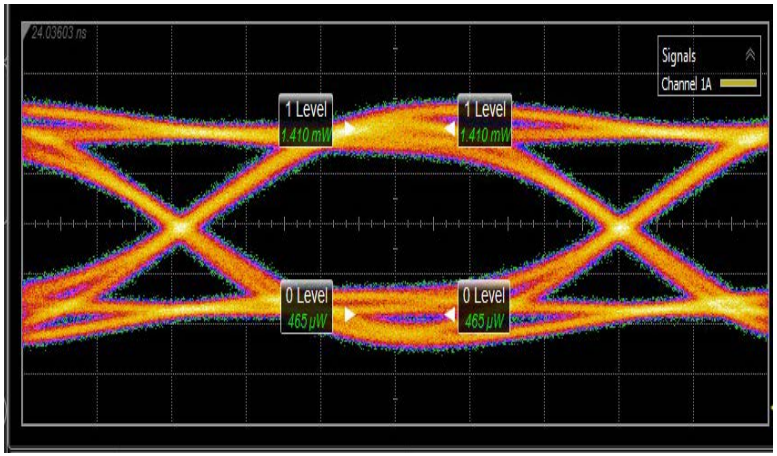
Future Applications – Silicon Photonics

- Silicon Photonics solutions are well suited for future cloud DC needs
  - Can meet very low cost targets
  - Can meet very long reach requirements
- Silicon Photonics will see it's market grow on both side of the reach spectrum
  - As DC sizes increase there will growth in long reach SMF interconnects
  - As rates increase there will be growth in short reach SMF interconnects
    - As copper and MMF reaches diminish
- Over time the barriers to deployment for Silicon Photonics will continue to decrease
  - More consideration for silicon photonics solutions in standards development
  - More silicon photonic providers -> More multi-source for the end user

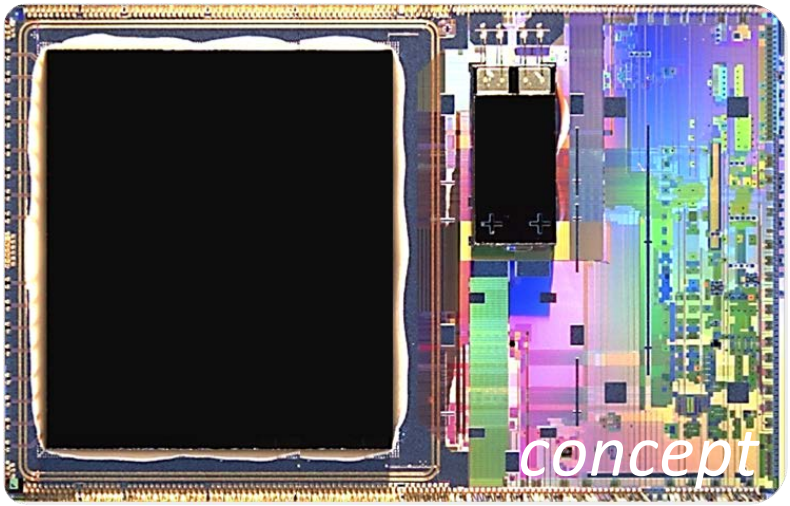
Future Applications - Silicon Photonics

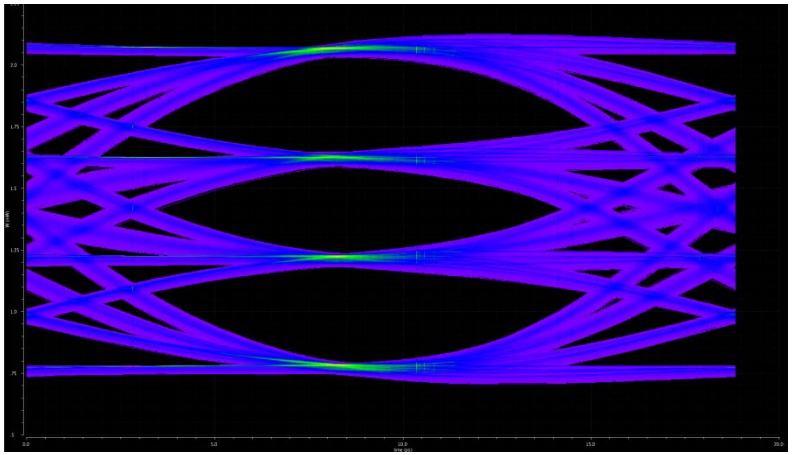
Today: 100G-PSM4



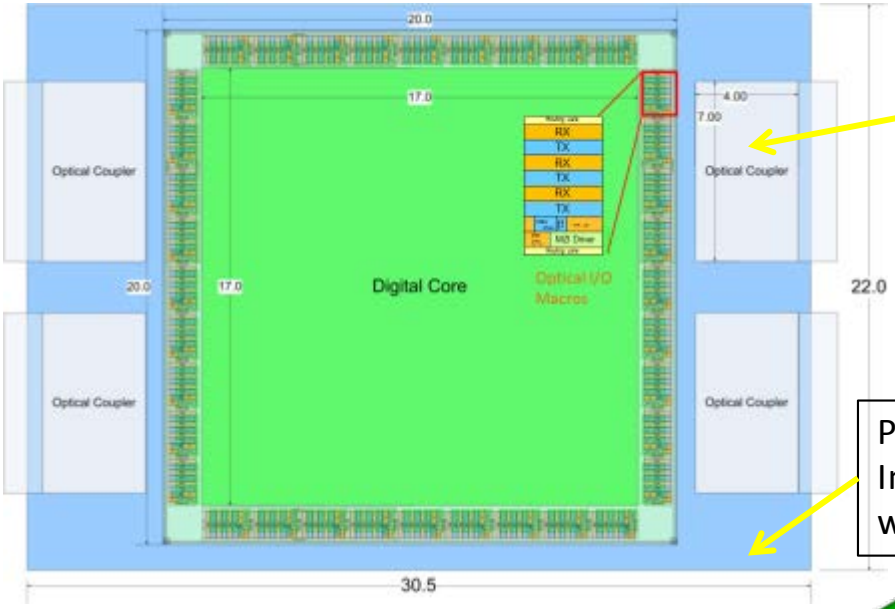


Tomorrow: 400-DR4 (PSM4)

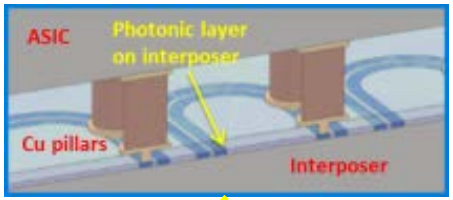


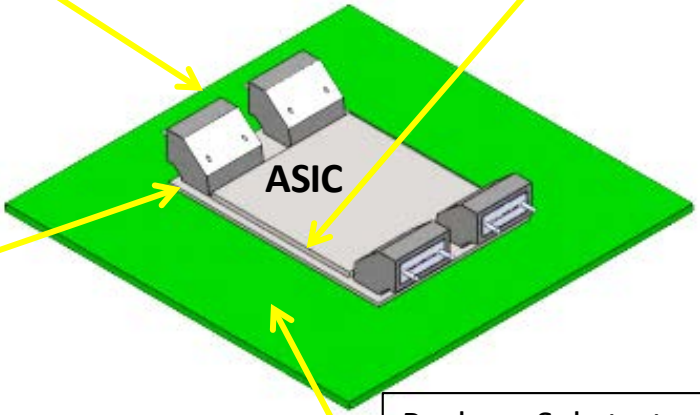


Future Applications – Silicon Photonics (Beyond)



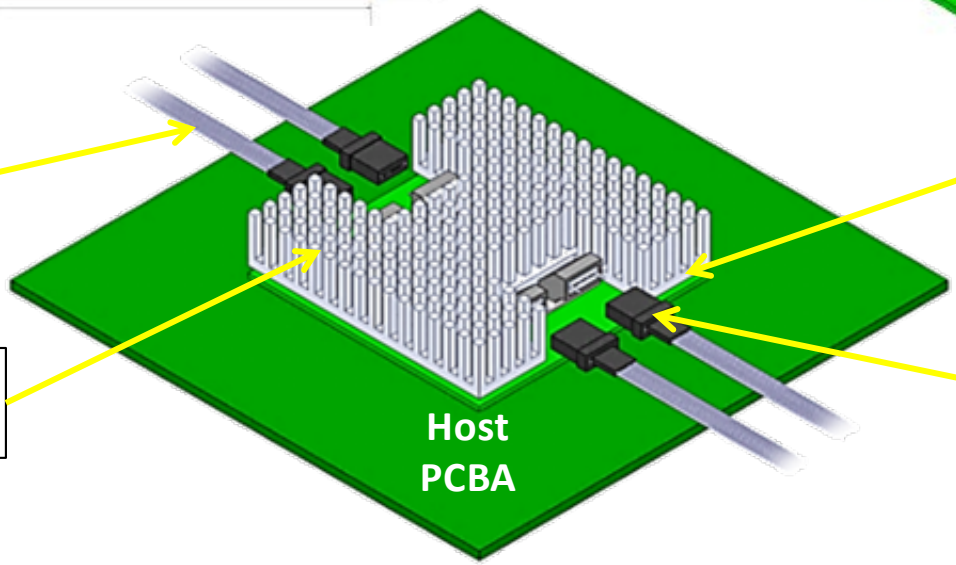
Optical coupler: interfaces between interposer and MT-ferrules





Photonic Interposer w/TSV

Optical fibers provide high-speed interconnect and provide supply of DC light to transmitters



Package Substrate:
- high & low speed IO
- power supply and
- mechanical support to interposer

Heat sink mounted on package

MT-Ferrules as example for pluggable fiber interconnect

Summary

- The “mainstreaming” of Silicon Photonics is well underway
  - Silicon Photonics offers unique benefits for cloud computing and other large scale datacenters
  - Enabling low cost and long reach is very attractive to the industry
- Many barriers to deployment have been reduced/removed over the years
  - Silicon Photonics are no longer proprietary links, but can interoperate with other solutions and technologies
  - These trends are likely to continue and propagate to other markets
- More benefits of Silicon Photonics are coming
  - Integration of optics can yield considerably lower cost than conventional module optics

Thank You

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