Silicon photonics opportunities and challenges for high speed transmission

March Chen

Electronic and Optoelectronic System Research Laboratories (EOSL)
Industrial Technology Research Institute (ITRI)

June 3rd 2019

Outline

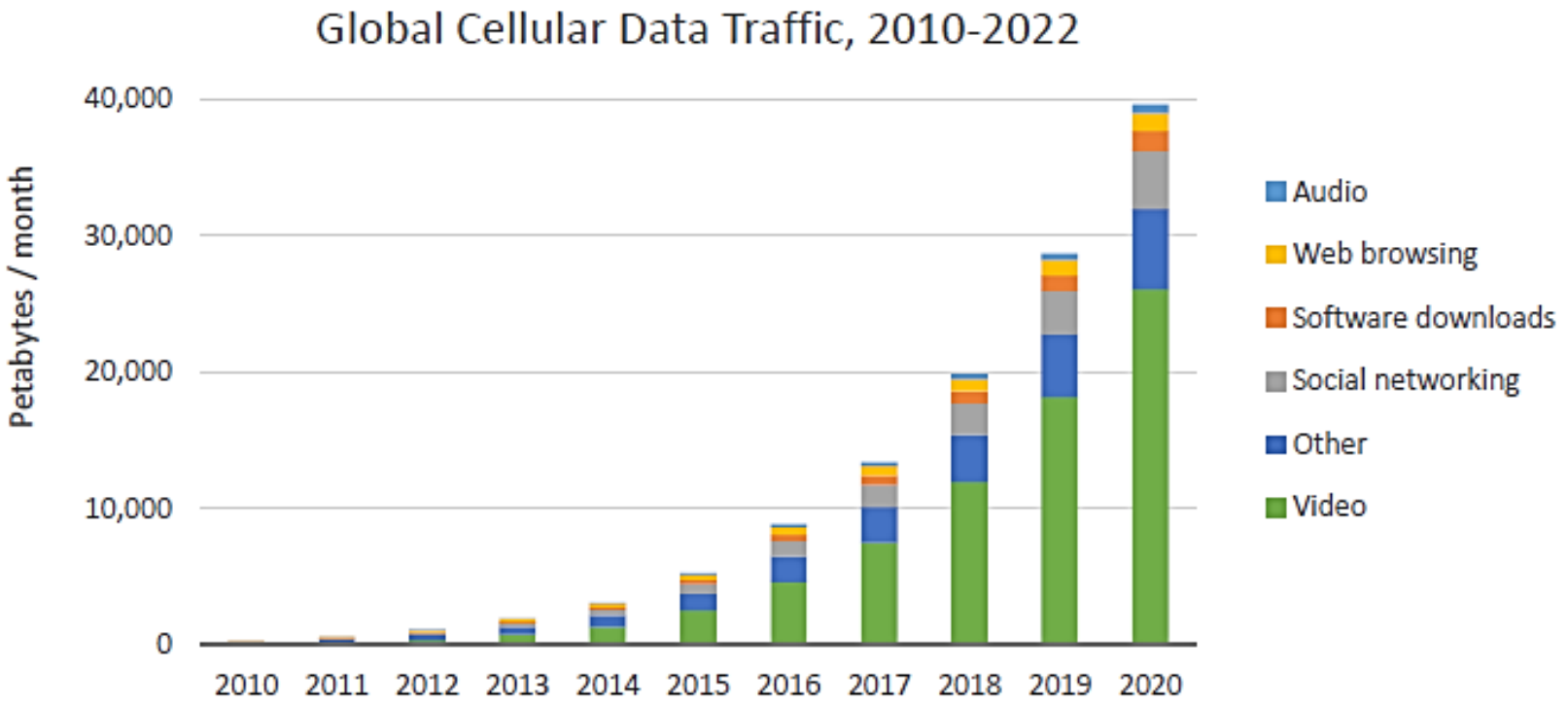
- Market trend and request
- Why silicon photonics
- Challenges
- ITRI silicon photonics platform
- Conclusion

The Future Life

- 10 or 20 years ago, could you imagine the life today?
- Could you imagine what the world will be after 20 years?

Source: skyworks website, http://www.skyworksinc.com/products_IoT.aspx

Data Traffic

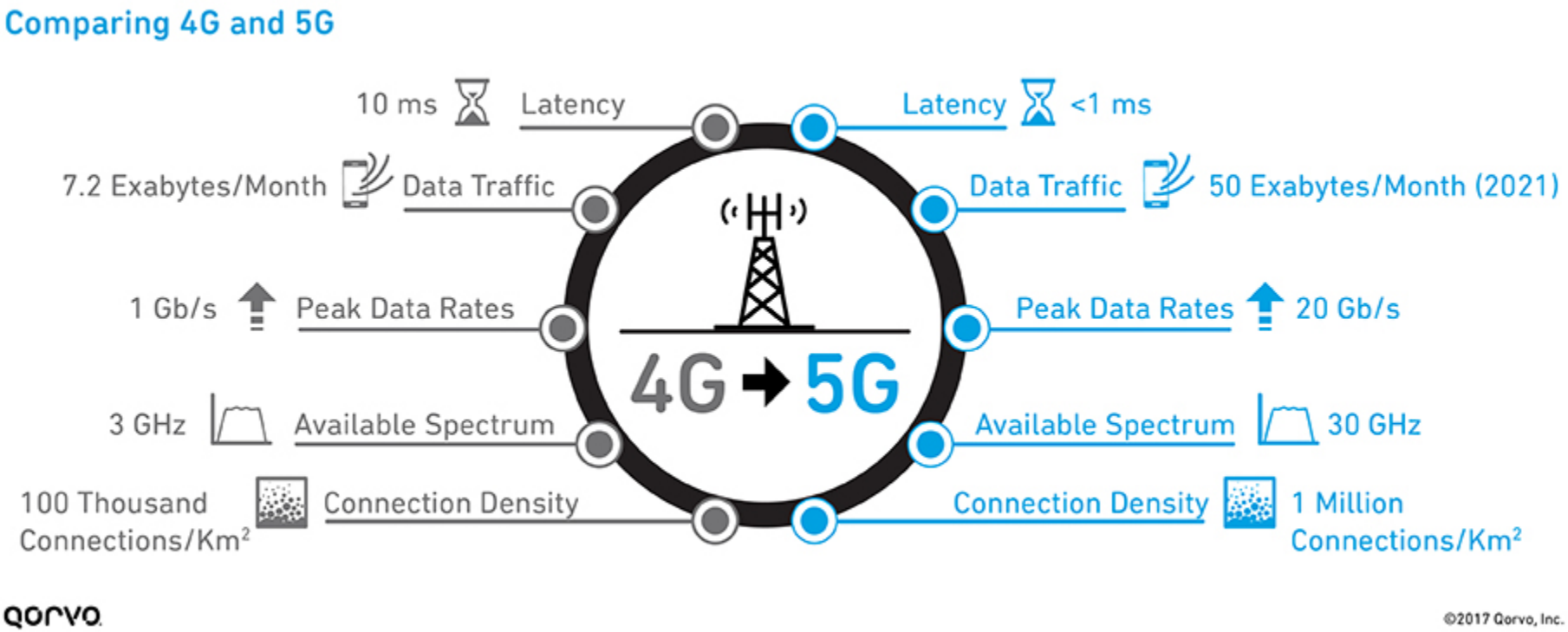


- Video transmission occupies most of internet pipe
- Grows up and up and up and…

➢ What action should we take for this mainstream?

Source: 5G Americas- 5G Services and Use Cases , 2017

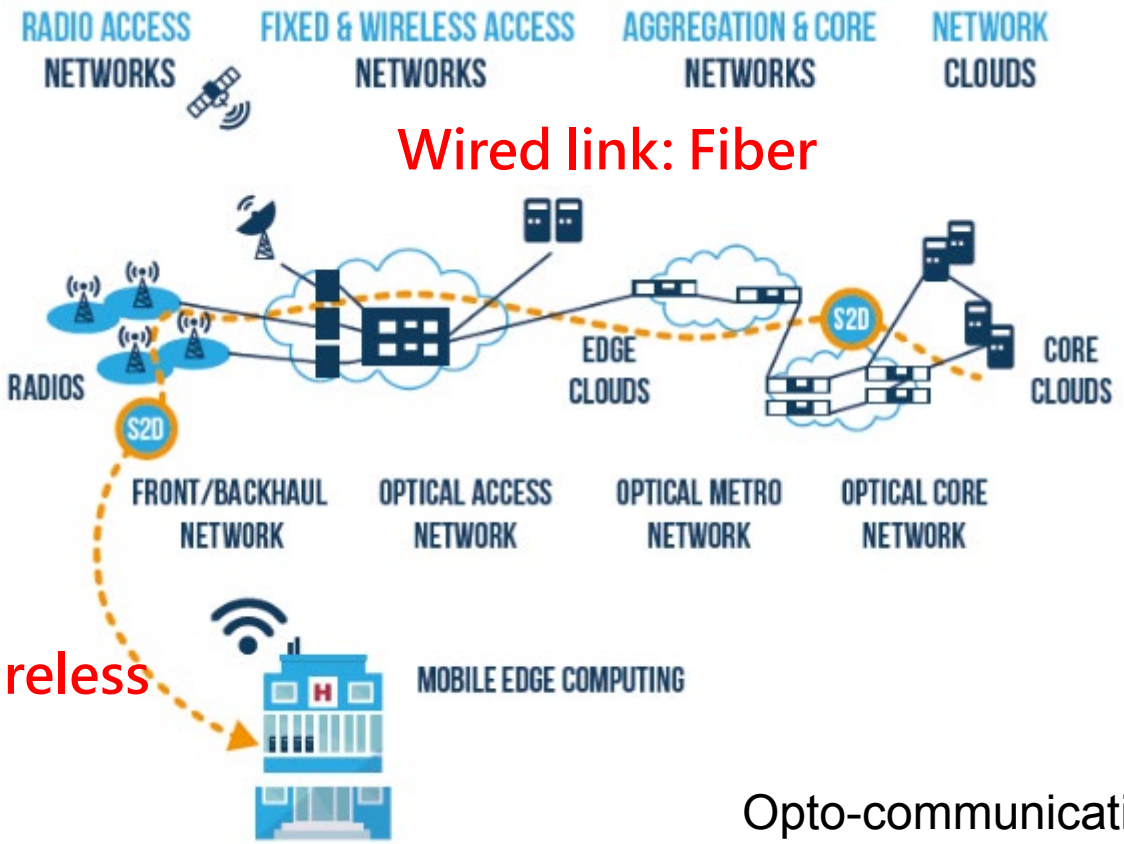
Specs Upgrade in 5G



- 10X to 4G
- 5G tries to solve wireless issue, then?

Source: Qorvo, Getting to 5G: Comparing 4G and 5G System Requirements, 2017

5G + Fiber Network



Deployment request:

- ✓ **High coverage**
- ✓ **High speed**
- ✓ **Low latency**
- ✓ **Low cost**

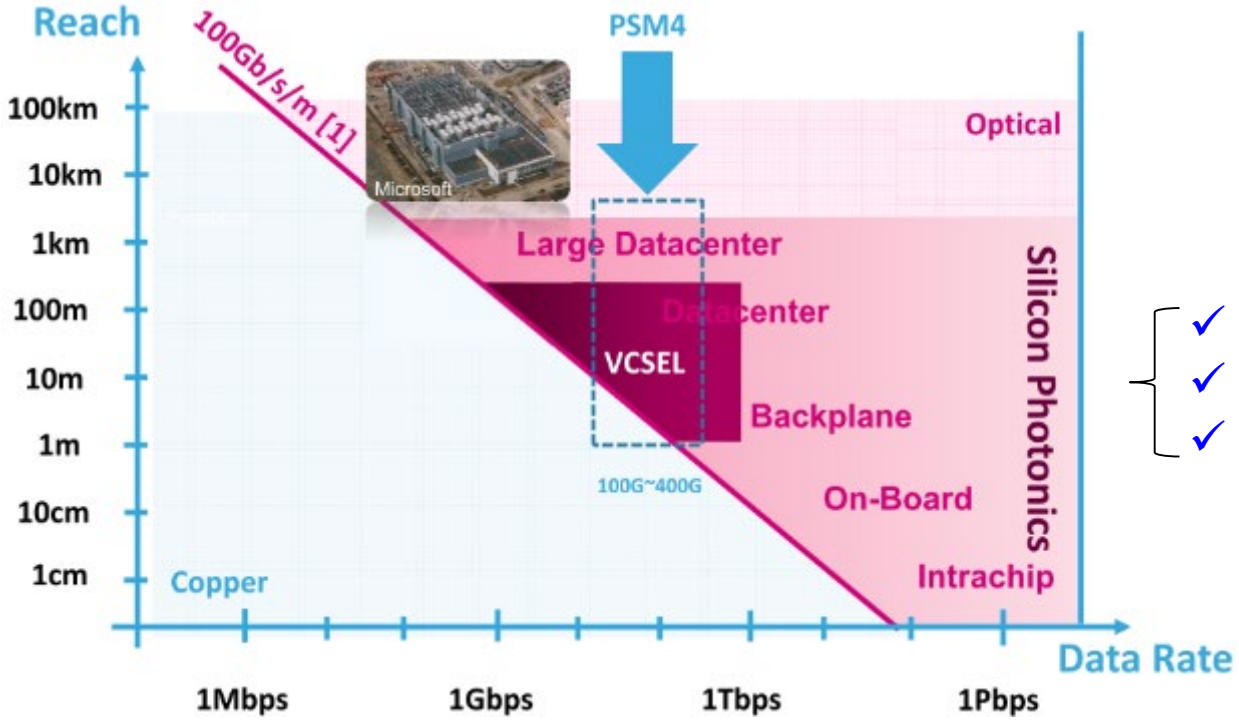
Opto-communication plays important role at:

- Base station
- Edge server
- Metro/core
- Data center

Source: 5GPPP, 2017

Why Optical Communication

- **Speed-length**



- ✓ Speed
- ✓ Cable length
- ✓ Power

- ✓ Electrical/optical link boundary 100Gbps·m
- ✓ Electrical link: only single λ
- ✓ Optical link:

  Multi-λ (CWDM, LAN-WDM, DWDM) per channel

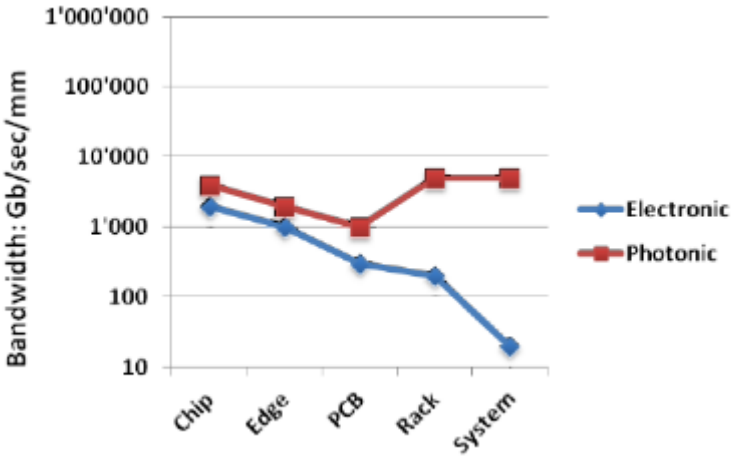
  Speed theoretically limited by electronics

Source: Krishnamoorthy, et al., IEEE J. Selected Topics in Quantum Electronics, vol. 17, no. 2, 2011

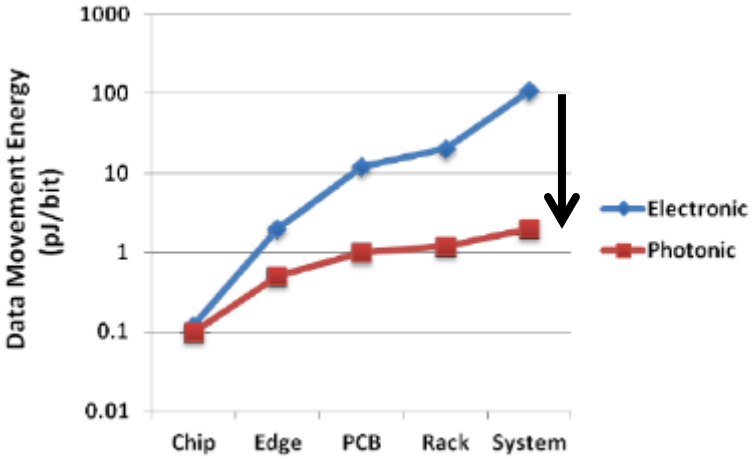
Why Optical Communication

- **Power consumption**

For exascale computing system



Bandwidth vs. system distance



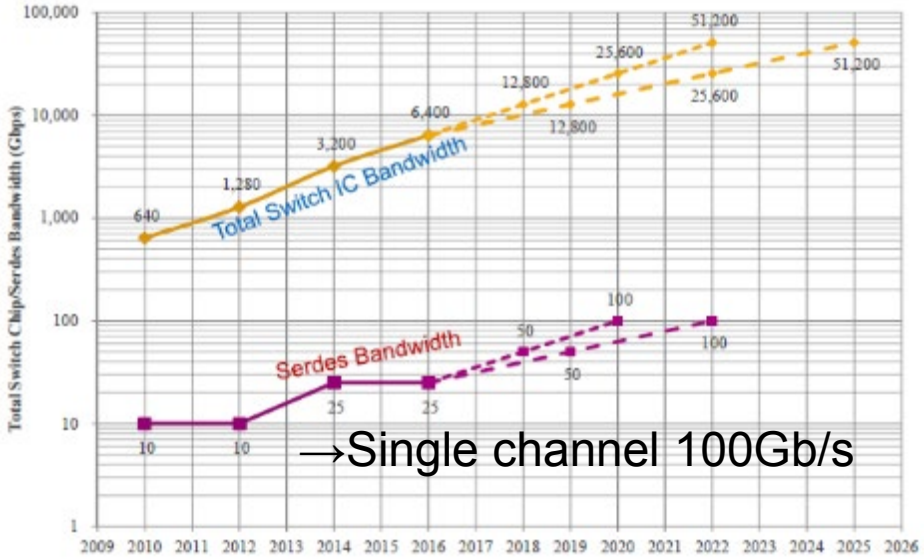
Energy vs. system distance

- ✓ Photonic interconnect shows superior performance in bandwidth and energy consumption compared to electrical one
- ✓ Photonic interconnects applied in a rack computing system reduce around 2-order power consumption

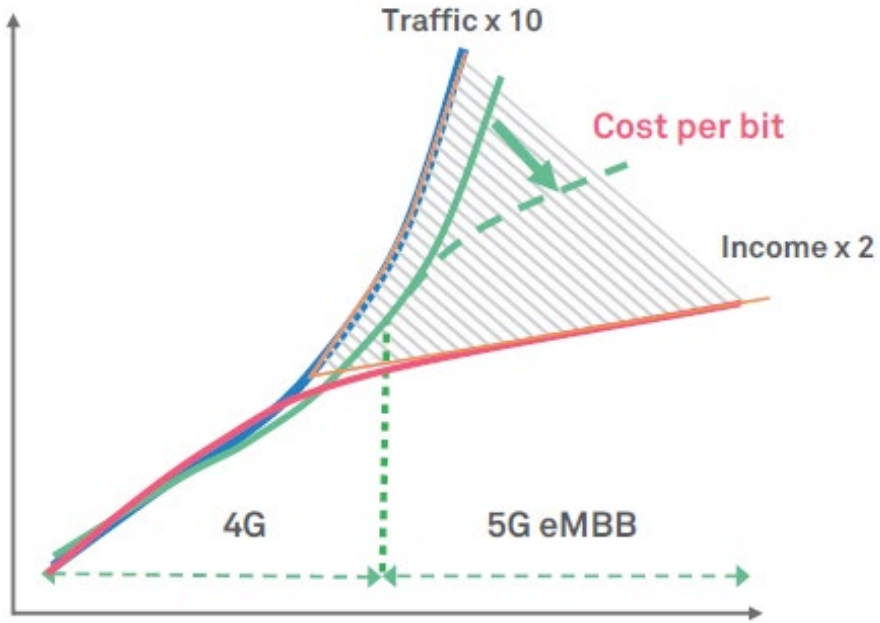
Source: U. S. Department of Energy, Top Ten Exascale Research Challenges, 2014

Issues When Data Traffic Increases

Switch bandwidth → 51.2T+



→Single channel 100Gb/s



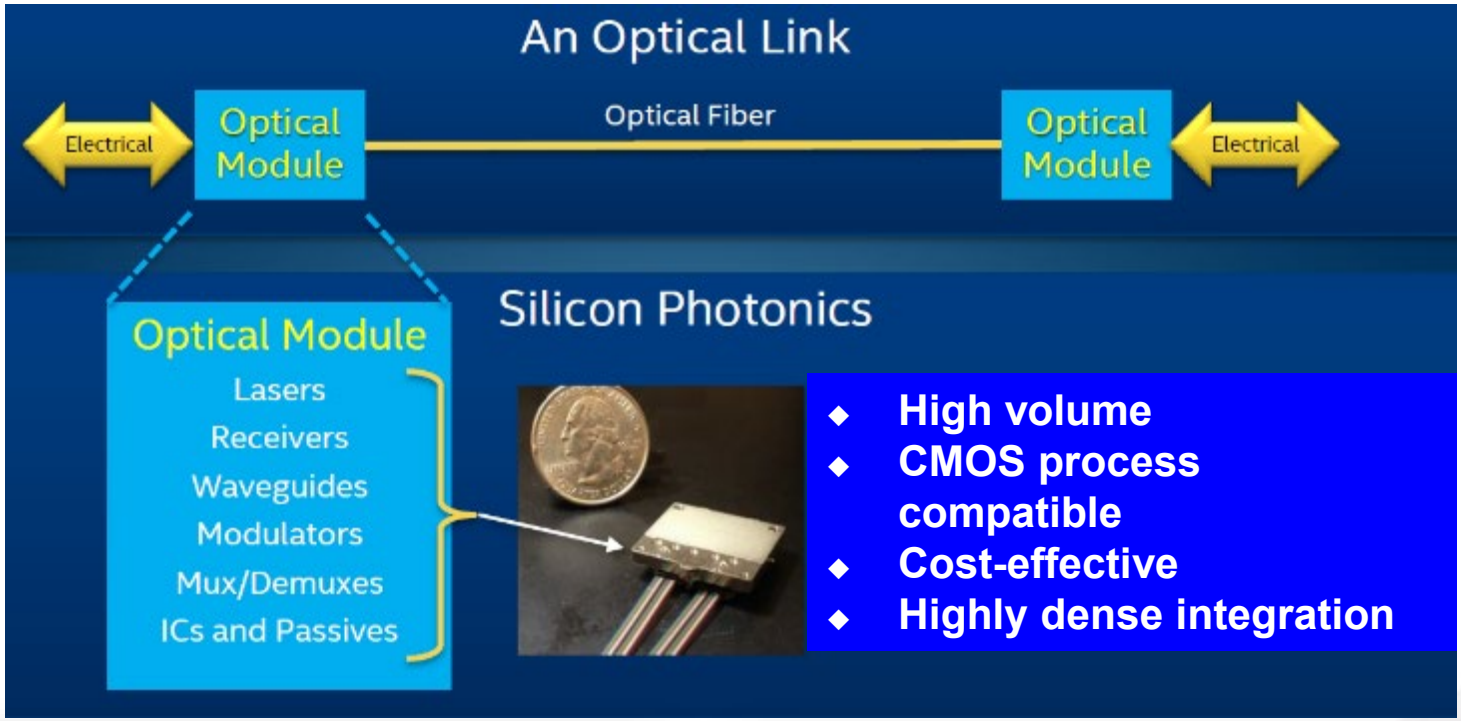
- **Technical requirement：**
  - **single channel data rate 100Gb/s**
  - **switch bandwidth 51.2Tb/s**
- **Photonic replaces electronics**
- **Interface is bottleneck**

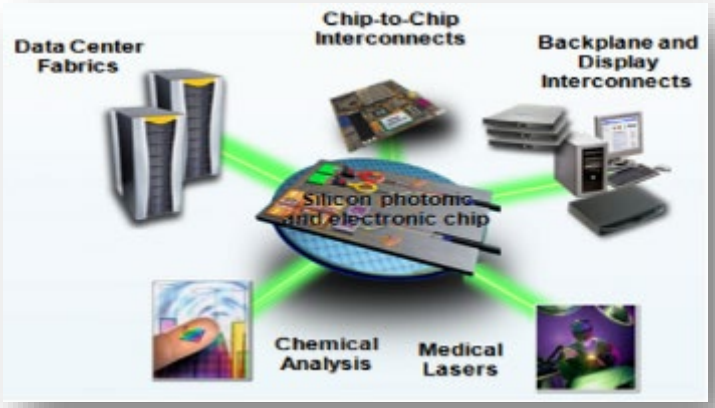
- **Technical development vs cost**

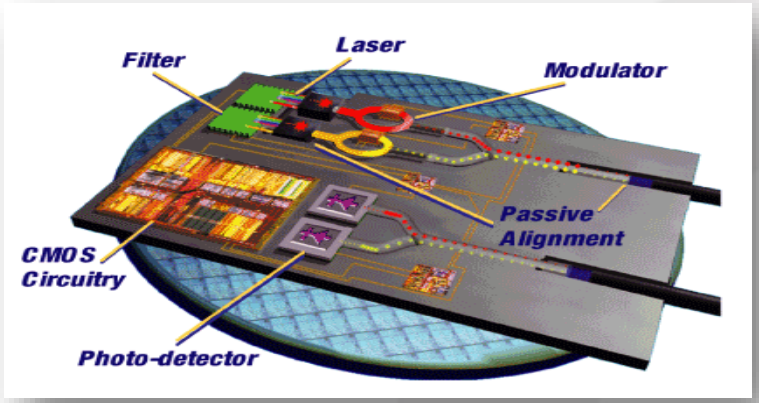
Silicon Photonics

Source: P. D. Dobbelaere, Luxtera, 2018
Huawei, ”5G PAM4 Technical White Paper,” 2018

What is Silicon Photonics?

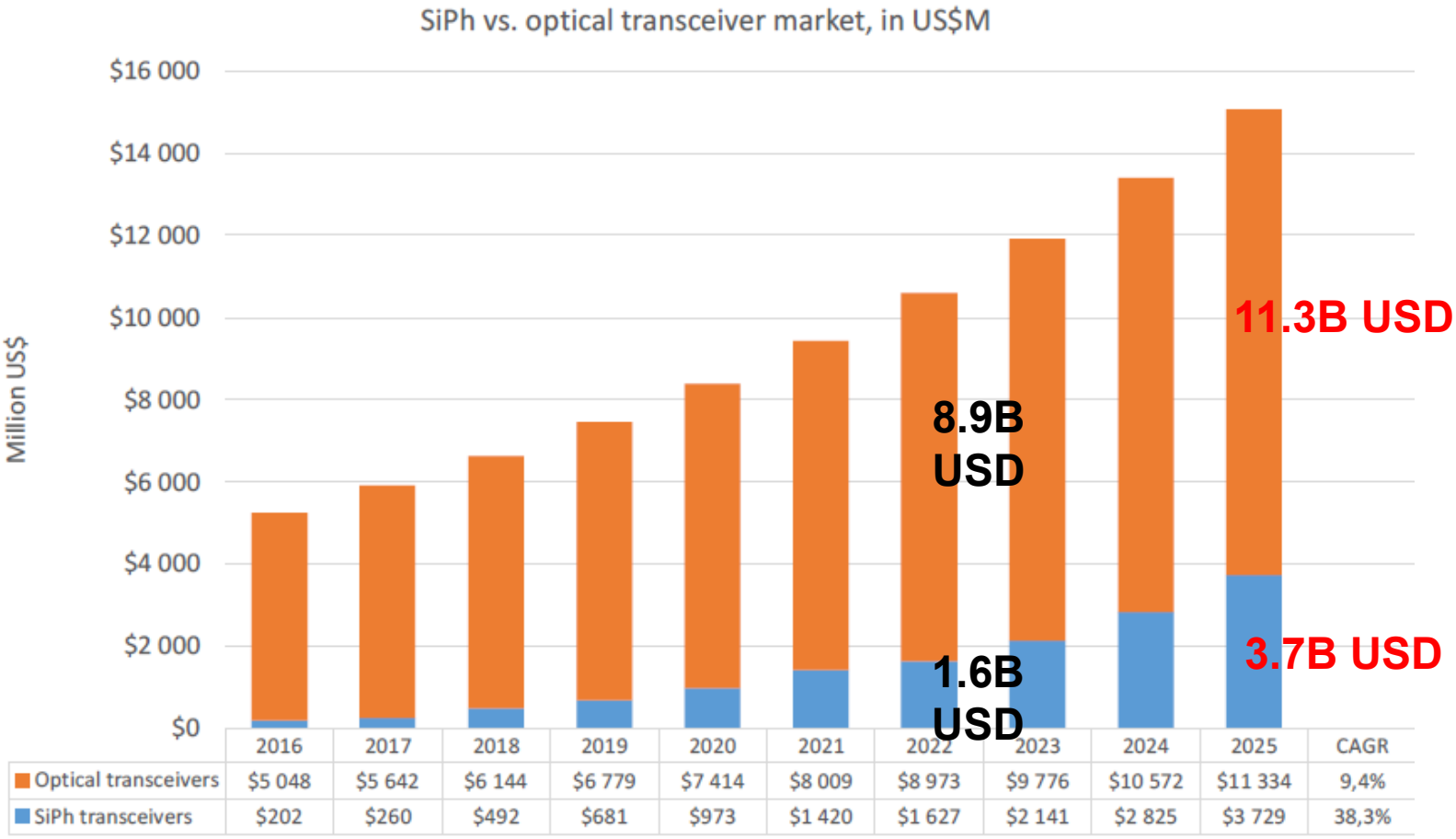






Source: Intel, Data Center Day, August 2015

Optical Transceiver Market Grows

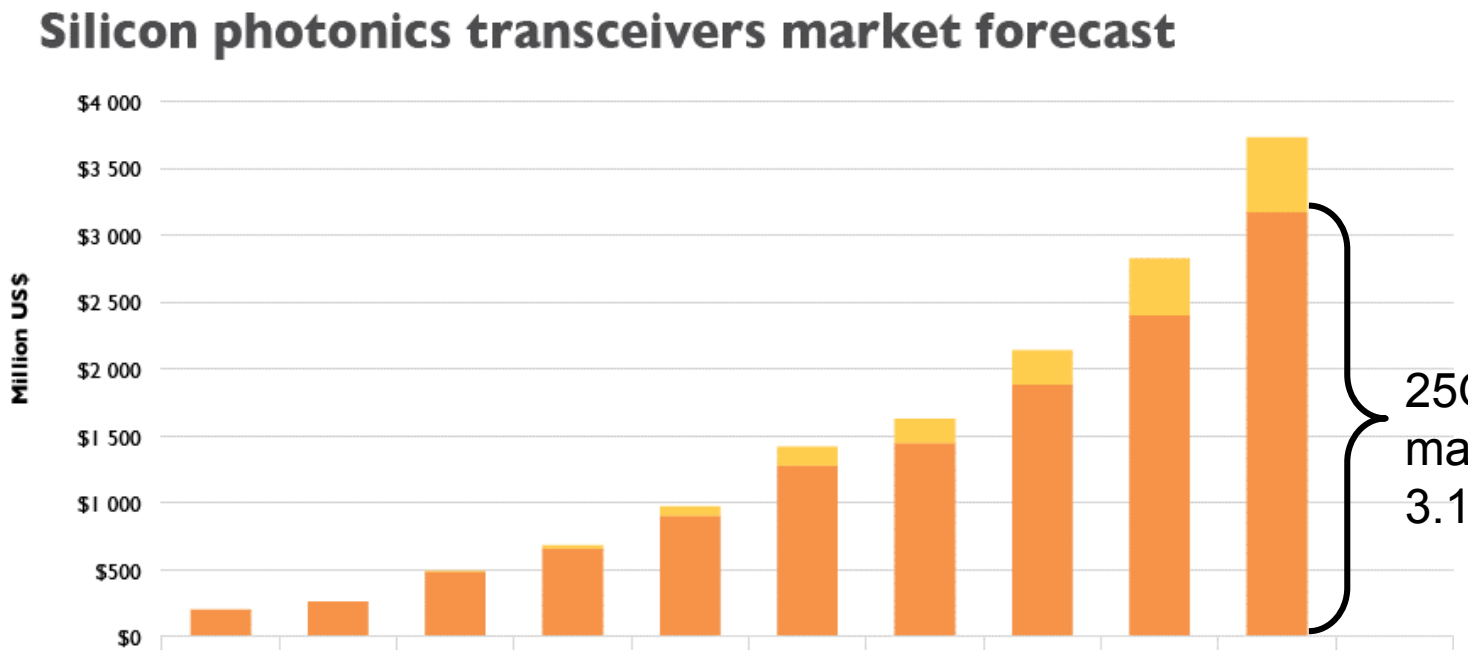


	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	CAGR
Optical transceivers	$5 048	$5 642	$6 144	$6 779	$7 414	$8 009	$8 973	$9 776	$10 572	$11 334	9,4%
SiPh transceivers	$202	$260	$492	$681	$973	$1 420	$1 627	$2 141	$2 825	$3 729	38,3%

- With data center and 5G application raising, optical transceiver market will grow to 10.5B USD in 2021, 15B USD in 2025

Source: Yole 2018

Silicon Photonics Market Forecast

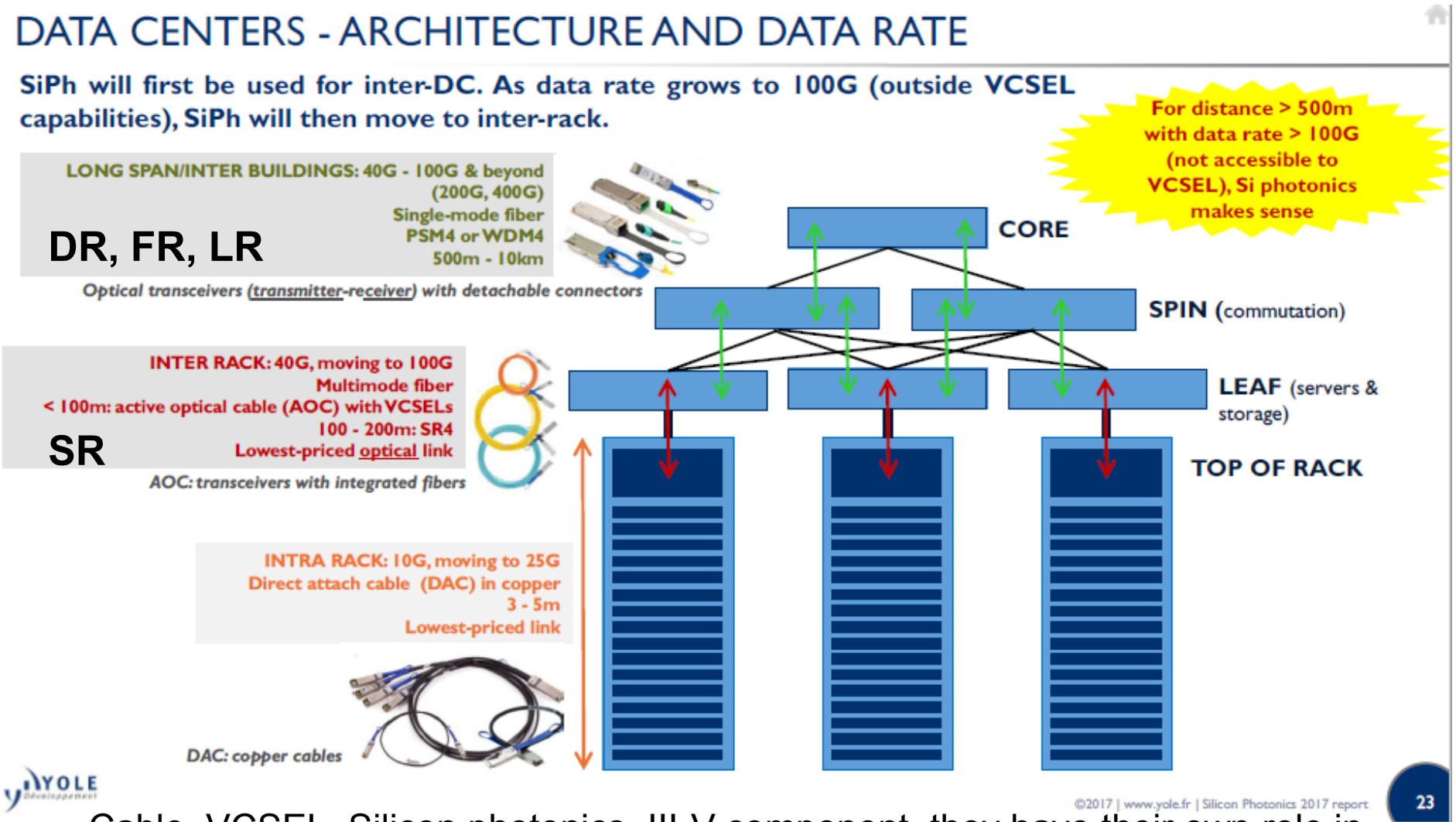


	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	CAGR
200G/400G Si photonics transceivers	$ 0	$ 0	$ 5	$ 21	$ 68	$ 142	$ 179	$ 257	$ 424	$ 559	95,9%
100G Si photonics transceivers	$ 191	$ 251	$ 475	$ 651	$ 900	$1 278	$1 448	$1 884	$2 401	$3 169	37,3%
40G Si photonics transceivers	$ 11	$ 9	$ 12	$ 9	$ 4	$ 0	$ 0	$ 0	$ 0	$ 0	0,0%

- 100G dominate the SiPh transceiver market，even >80% in 2025
- 200G/400G market grows slowly in 2019
- 400G product comes this year but market is still a few years away

Source: Yole 2018

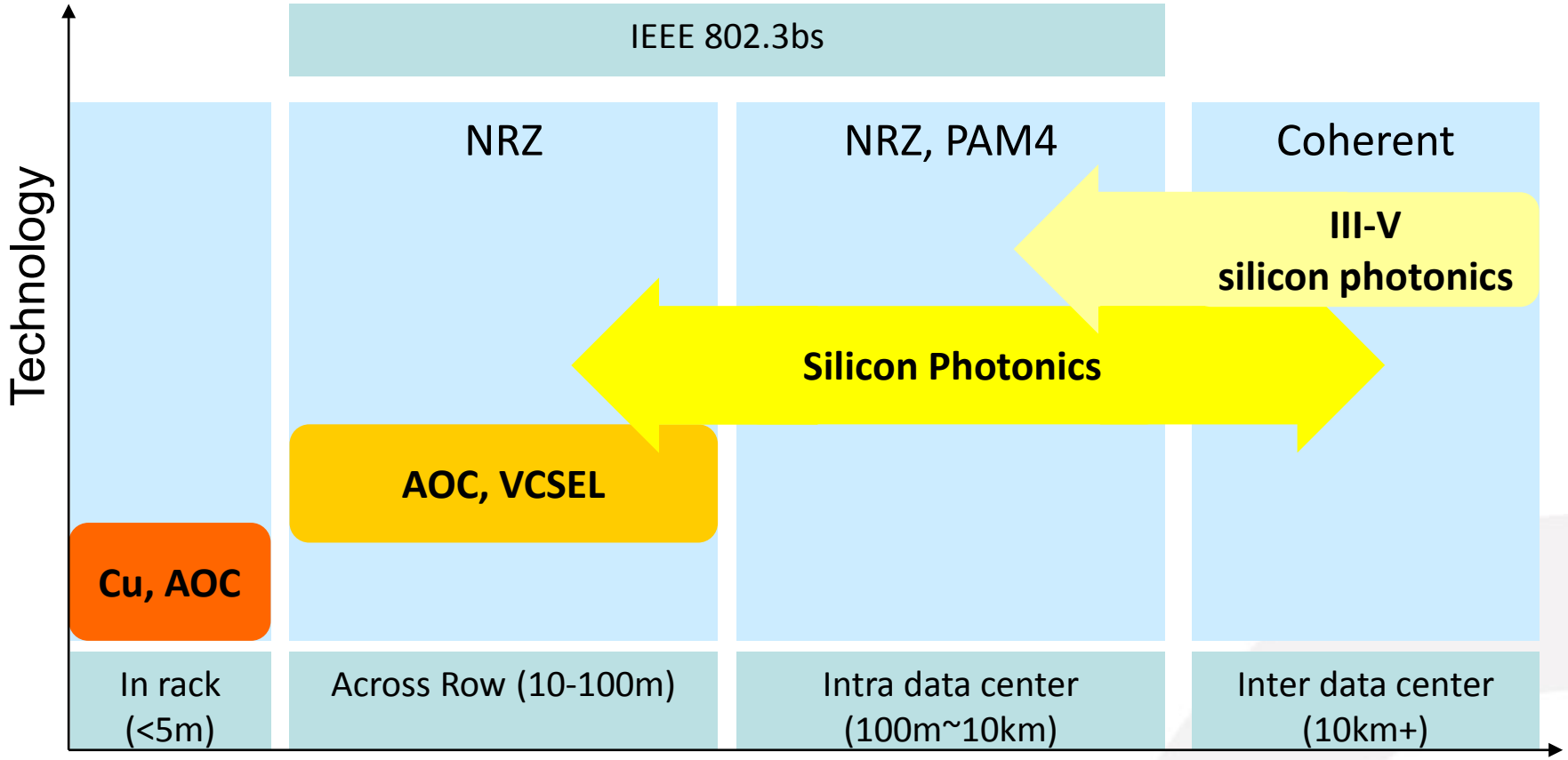
Silicon Photonics in Data Center



- Cable, VCSEL, Silicon photonics, III-V component, they have their own role in data center transceiving market

Source: Yole 2018

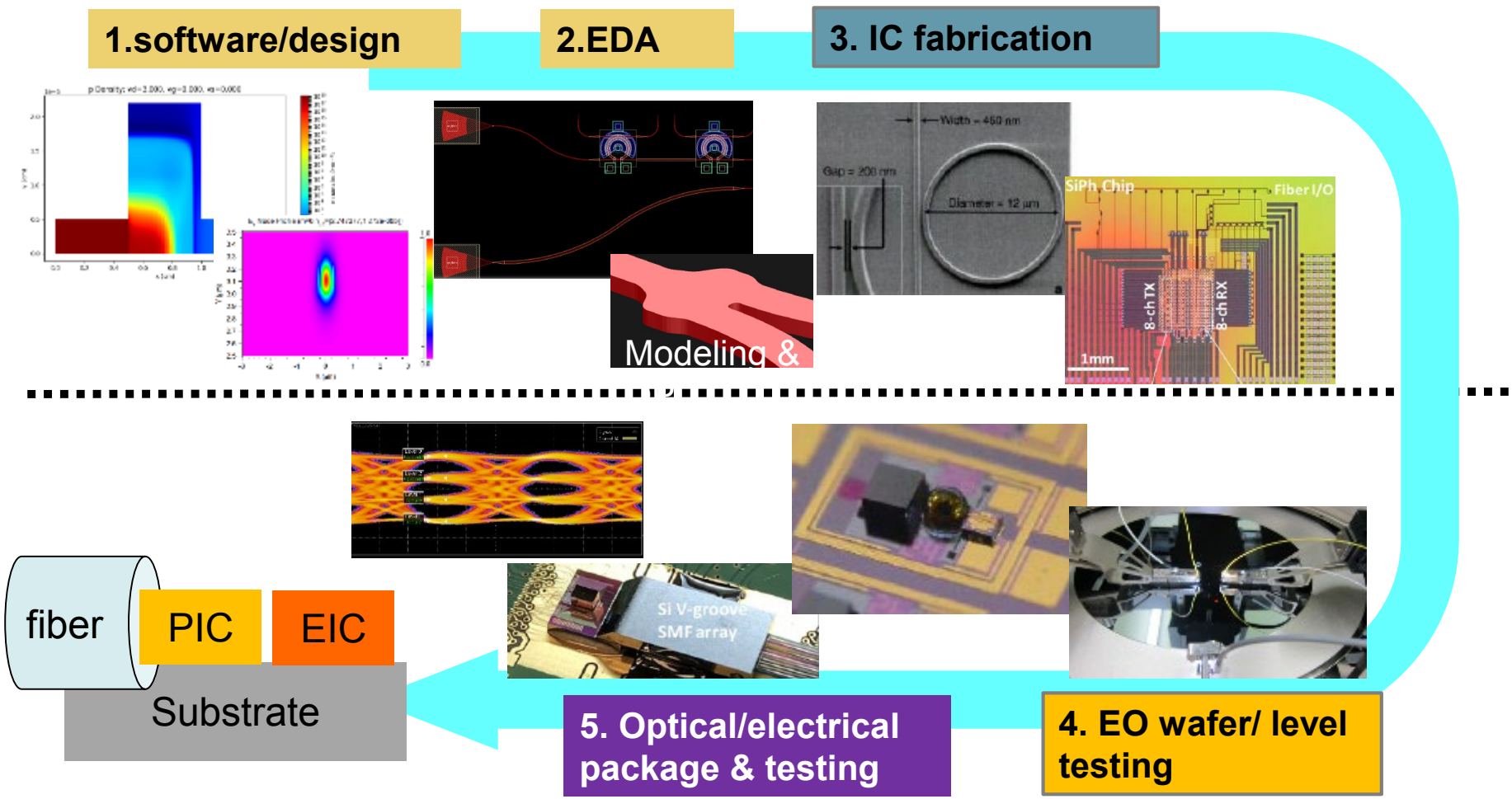
What Silicon Photonics Competes with



- AOC, VCSEL, silicon photonics, long-haul optics own the role themselves in data center transceiver market
- Silicon photonics is potentially suitable for all transmission links

Source: Intel, Data Center Day, August 2015

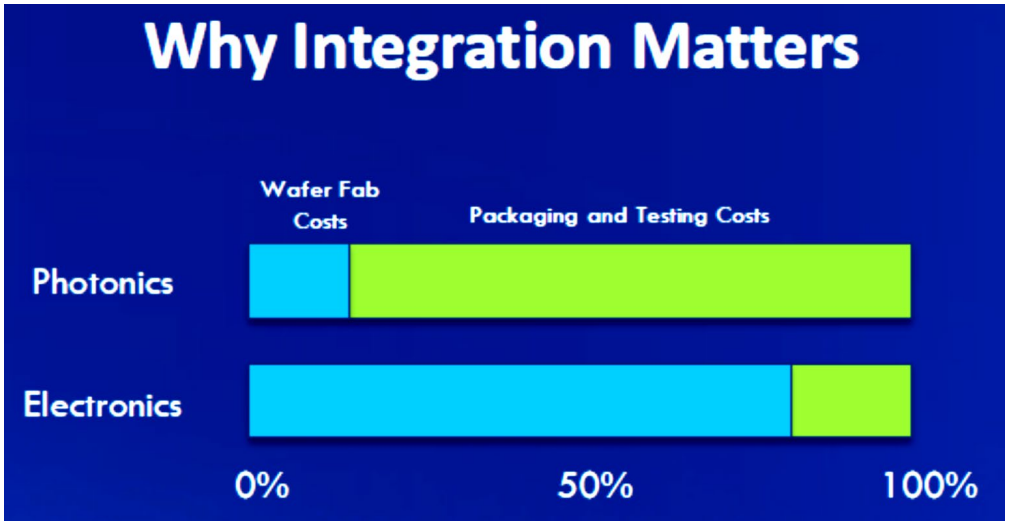
Silicon Photonics Challenges



How to fit photonic events into silicon production chain?

Source: T Chen, Mentor, 2018
P. D. Dobbelaere, Luxtera, 2018

Packaging & Testing Matters



Wafer fab costs

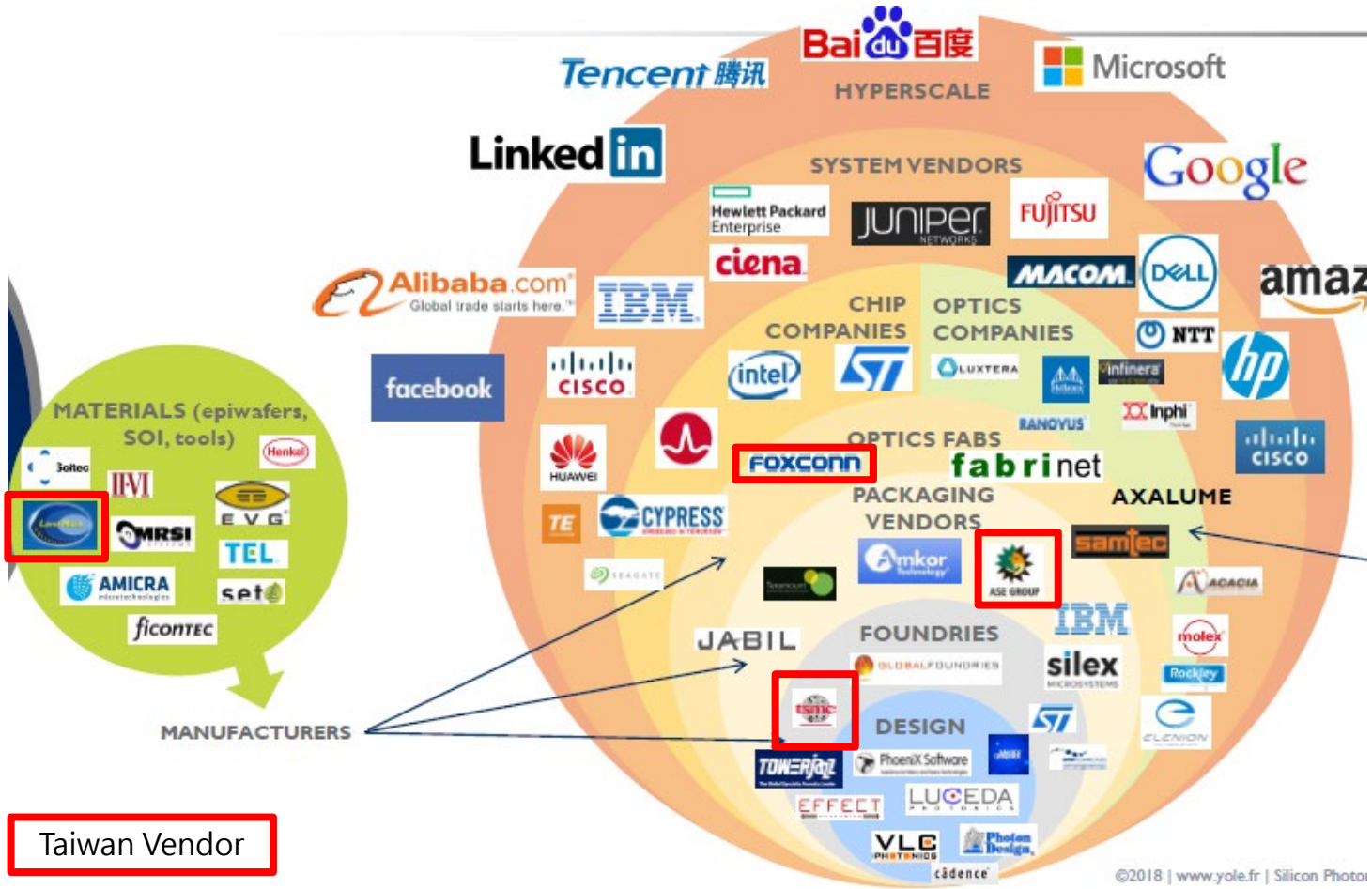
Packaging and testing cast

- In electronic IC process, 80% of cost is wafer processes
- Om photonic IC process, packaging and assembly are more than 80%！

Wafer fab realizes optical components on silicon semiconductor process, but packaging and testing are the key for commercialization

Source: T. R. Mika, POET, 2018/6

Worldwide Supply Chain



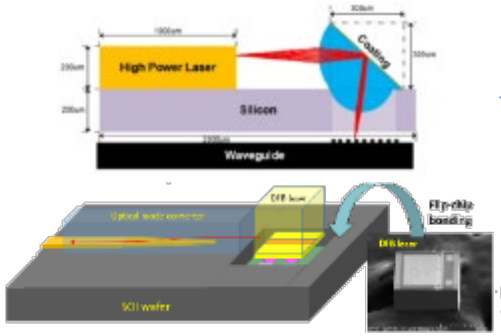
Taiwan Vendor

- Worldwide supply chain for production is now integrated by several leading companies
- To build up silicon photonics R&D platform to accelerate Taiwan's silicon photonics supply chain forming

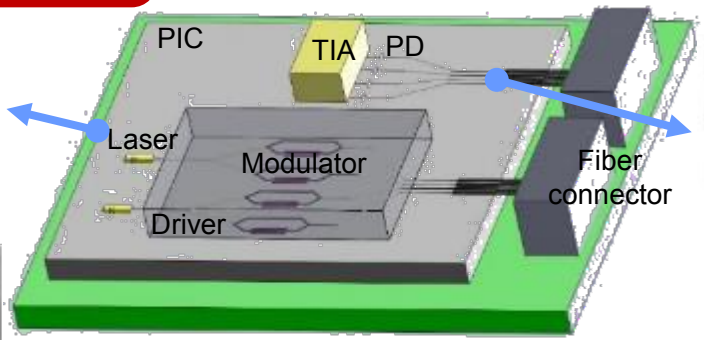
Source: Yole 2018

ITRI Silicon Photonics Technical Platform

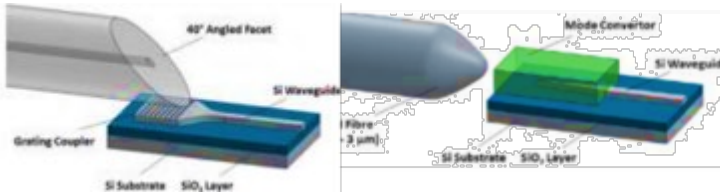
B PIC packaging platform (Laser)



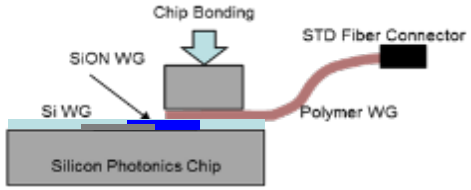
Laser integration



B PIC packaging platform (Fiber & polymer WG)



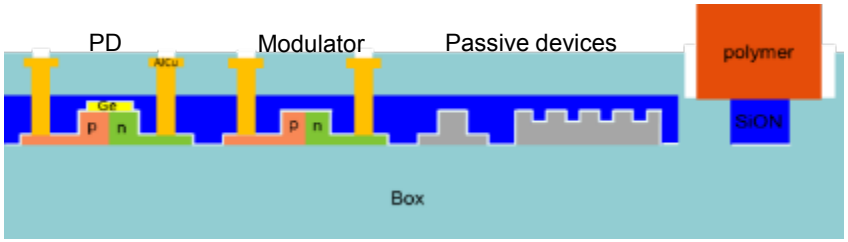
Low loss fiber coupling

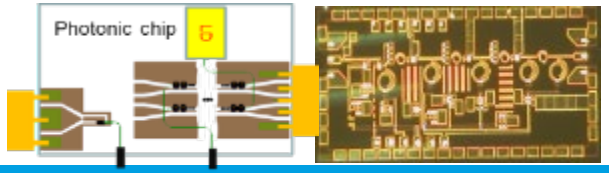


Multi-channel polymer WG array

Multi-channel silicon photonics transceiver module

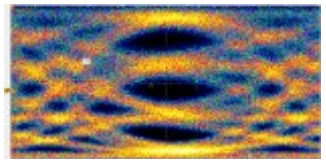
A PIC integration

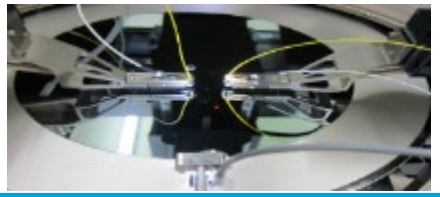




- Device design and integration
- EIC+PIC integration

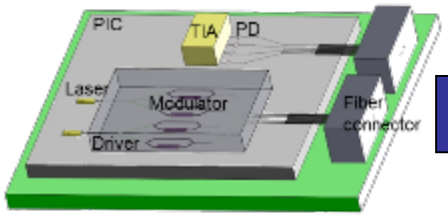
C High speed testing platform





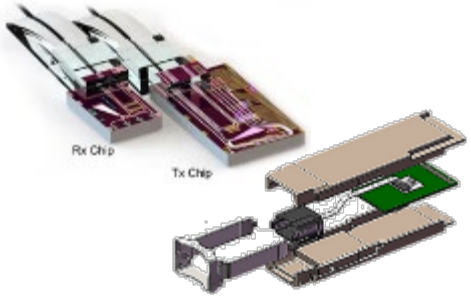
- Wafer level testing
- High freq. optical testing
- PAM4 analysis

Application of Photonic Integration



Silicon photonics technology platform

≧1Tb/s optical transceiver



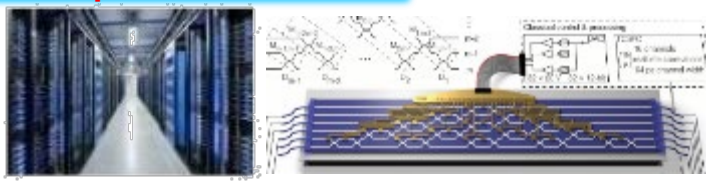
Reference: Browave, Mellanox

Co-Packaged Optics Switch

Reference: Luxtera

51.2Tb/s switch

5G / quantum tech.

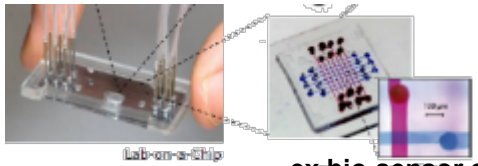


HPC/CPU

LiDAR
3D sensing
gyro

ex IR camera chip

Medical



ex bio-sensor chip

High Speed Opto-Electronic Testing Platform

- LIOS – Lab for integrated opto-electronics systems
- 100Gb/s PAM4 Tx/Rx device/module test

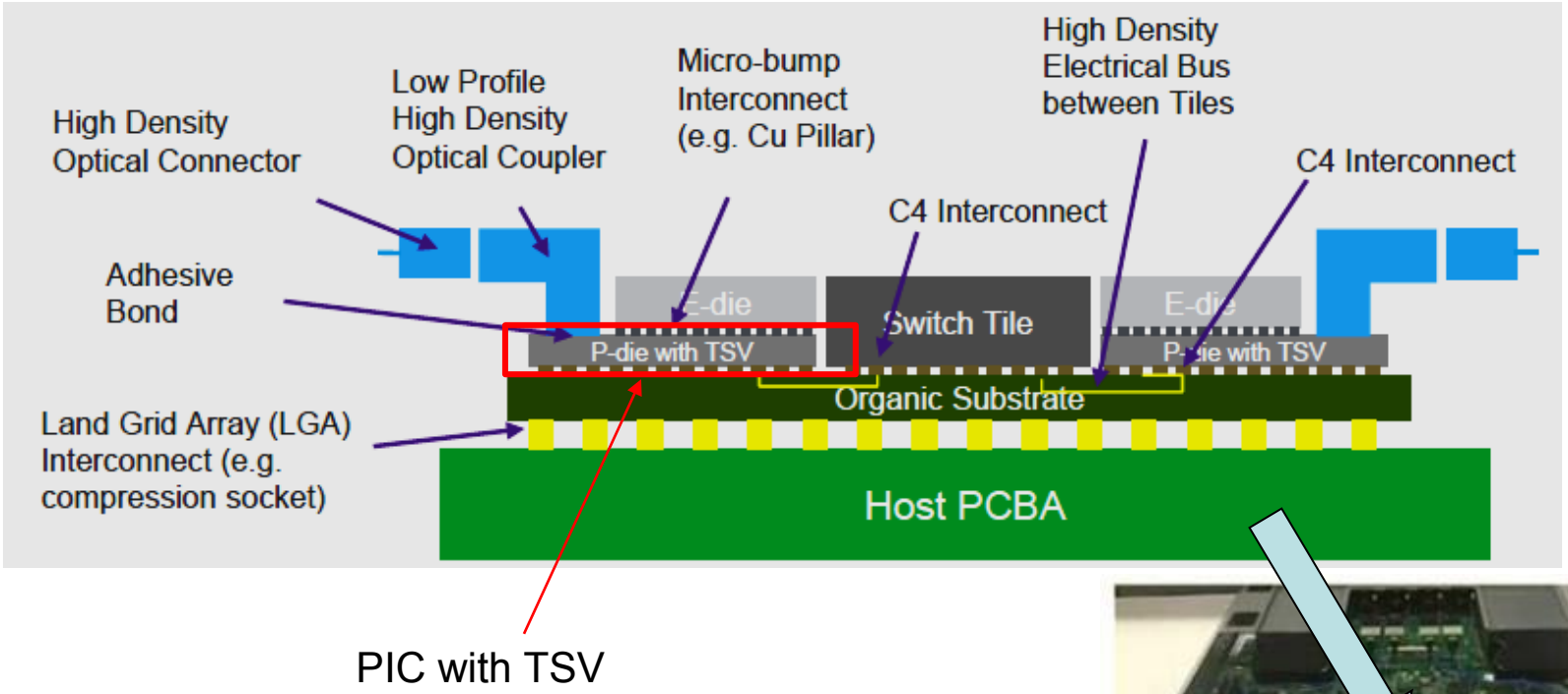
- Automatic passive device insertion loss test
  - Multiple channel allowed, ex 1x2, 1x4, 2x2, etc.
  - 8~20° fiber angle (not adjustable during test)
  - Full wafer map automatic measurement
  - O-band and C-band

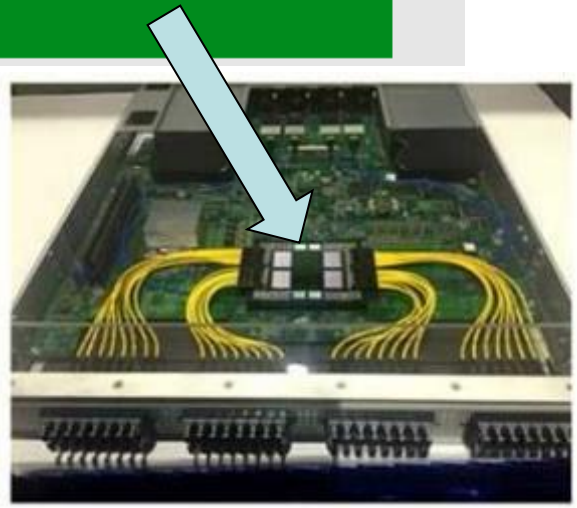
- Automatic active device test
  - CP sorting purpose
  - Only for fixed wavelength, signal pattern and scope receiver condition

- Flexible manually test capability
  - On wafer, on chip, on board test
  - 2 RF, 2 fiber, 2 DC deployment

Silicon Photonics + 3DIC

Luxtera Co-package for switch





- High density, high speed bus → TSV make sense

Source: P. D. Dobbelaere, Luxtera, 2018

Conclusion

- People should do something to take the rapid growth of data traffic, one of them is silicon photonics
- ITRI build up a silicon photonics design, process, packaging and testing platform for the goal of 100Gb/s PAM4 data rate PIC/EIC integration
- Once silicon photonics works, it will drive many applications to be integrated by CMOS process, such as LiDAR
- ITRI would like to have deep collaboration with industry in silicon photonics related technologies and applications through the platform

Thank You