Silicon Photonics Market and Applications: from Optical Transceivers to Emerging Uses

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PIC INTERNATIONAL CONFERENCE

ANGELTECH

YOLE Intelligence

CONTENT

SILICON PHOTONICS – YOLE'S SEGMENTATION

Markets & Applications Overview

MARKETS		Communication & Infrastructure				Others		
		Datacom (Networking – IM-DD)	Telecom (Networking – xWDM)	Telecom (Networking – Wireless)	Datacom (Processing)	Consumer	Automotive	Medical	Industrial
Silicon Photonics APPLICATIONS		Fiber-Optic Communication			Communication/ Processing	Sensing			
END-SYSTEMS		Networking servers		5G base stations	Computing servers, HPC, quantum	Wearables, smartwatches	Cars, robotic vehicles	Diagnostic tools	Electronic noses, environmental sensors
MODULES	Transceivers	Pluggable transceivers	Pluggable transceivers	Pluggable transceivers	Embedded optical interconnects				
	Interconnects	CPO engines			In-package Optical I/O engine				
	Processors				Photonic processor, photonic qubits module				
	Sensors					Bio chipset	Lidar, FOG	Immunoassay	Environmental sensing module
SILICON PHOTONICS UNIT		Si photonics die + laser	Si photonics die + laser	Si photonics die + laser	Si photonics die (lasers are remote)	Si photonics die + laser	Si photonics die + laser	Si photonics die (consumable)	Si photonics die + laser
SILICON PHOTONICS FUNCTIONS		Waveguides, splitters, modulators, photo detectors			Waveguides, splitters, modulators, gratings, photo detectors				
VOLUME in 2023		> 1 Munits	> 100 Kunits	< 100 Kunits	< 50 Kunits	< 50 Kunits			

SILICON PIC AND OTHERS

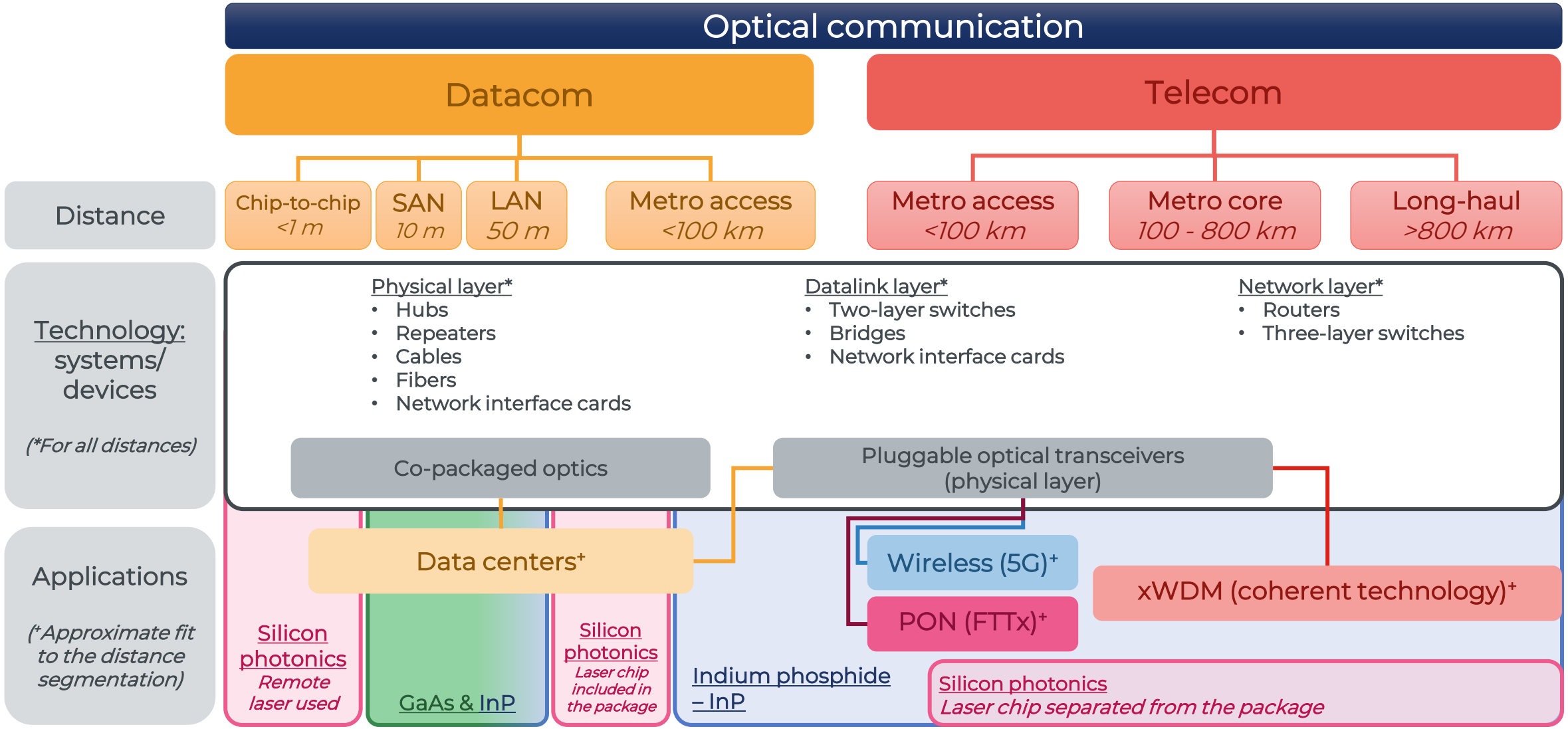
Comparison with other PIC platforms

Silicon photonics has been the « new kid on the block » in the photonics industry.

	InP	SiPh	SiN	Glass	Polymer	Silica	LiNbO3
Passive components	++	++	+++	+++	+++	+++	Hybrid
Polarization components	++	++	++	+	+	Hybrid	Hybrid
Lasers	+++	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid
Modulators	+++	++	+	Thermal	+++	Hybrid	++++
Switches	++	++	+	+	+	+	Hybrid
Optical amplifiers	+++	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid
Detectors	+++	++	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid
PROs	Best for laser integration	Best for electronic/optical integration	Low cost Small size	Simple process, low cost	Compatible with Si/InP platforms	Low losses Low cost	Very good modulation function
CONs	High cost and low yield for components integrating other elements	No light generation	Material properties are process-dependent	Few functions are possible	Reliability / thermal management issues	No active functionalities	Not a thin-film tech yet
INDUSTRY STATUS	HIGH-VOLUME LASER	RAMPING UP TO high-volume transceiver	LOW-VOLUME PRODUCTION	PRE-SERIES	R&D/ QUALIFICATION	HIGH-VOLUME couplers	HIGH-VOLUME modulators

GLOBAL CONTEXT

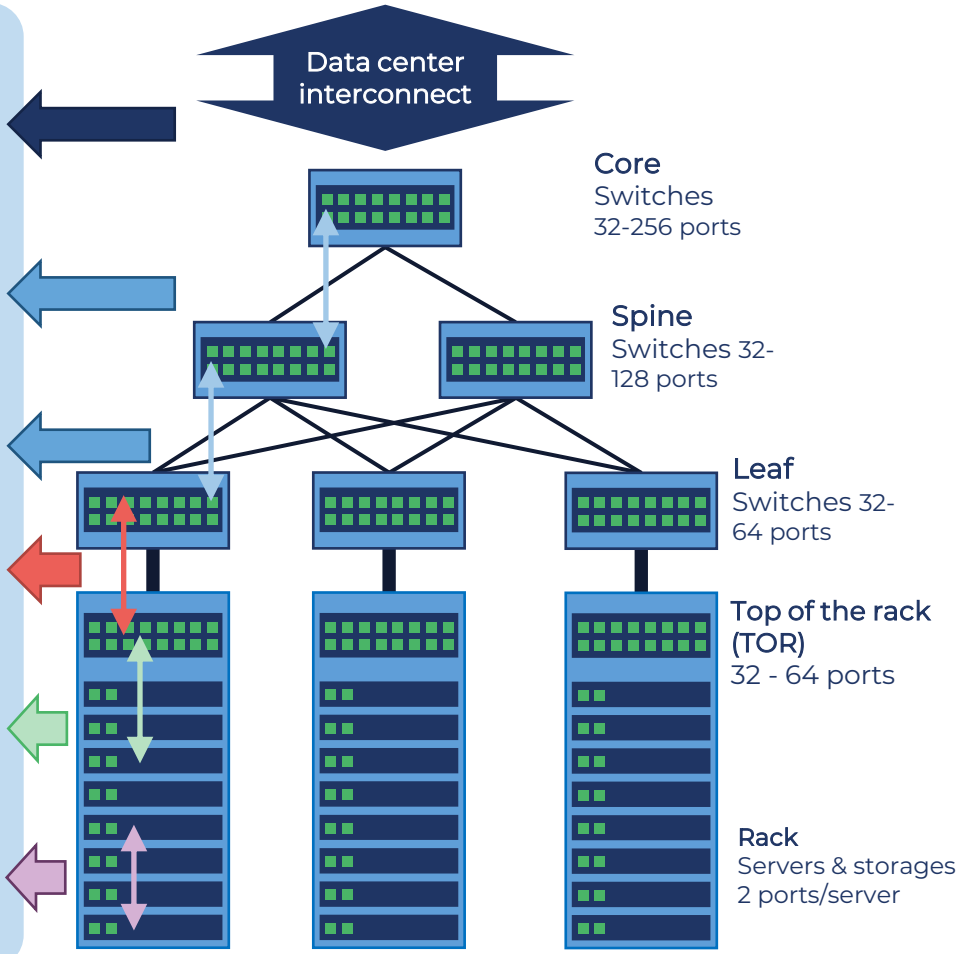
Classification of optical communication technologies



GLOBAL TRENDS IN DATACOM

Application landscape of datacom optical modules

	Typical distances		Last generation (2020)	At present (2023)	Next generation (2025)
Among data centers	80 km – 120 km	INTER DC Among campuses	400G ZR/ZR+* *(since 2021)*	Domain of Silicon Photonics technology: 400G ZR*	800G ZR*
				*Coherent (TELECOM) technology	
Spine – core	10 km – 40 km	INTRA DC Among buildings	100G LR1/ER1 400G LR4/ER4	800G LR8	1.6T 2LR4/LR8
Leaf – spine	500 m – 2 km	INTRA-DC Among buildings	Domain of Silicon Photonics technology: 400G DR4/FR4	800G DR8/FR8	1.6T DR8/2FR4/FR8
				CPO (*delayed for volume deployment*)	
TOR – leaf	70 m – 300 m	INTER-RACK Within buildings	400G SR8/SR4.2	Domain of Silicon Photonics technology: 800G SR8	1.6T SR8 vs 1.6T DR8 200G VCSEL vs Si PIC
Server – TOR	2 m – 50 m	INTRA-RACK Within room	100G AOC/DAC	200G AOC/DAC	400G AOC/DAC
Server – server (AI/ML machines)	< 2 m	Within room	Copper links	Domain of Silicon Photonics technology: Optical I/O (PCIe, CXL and UCIe standards) NEW	Optical I/O (PCIe, CXL and UCIe standards)



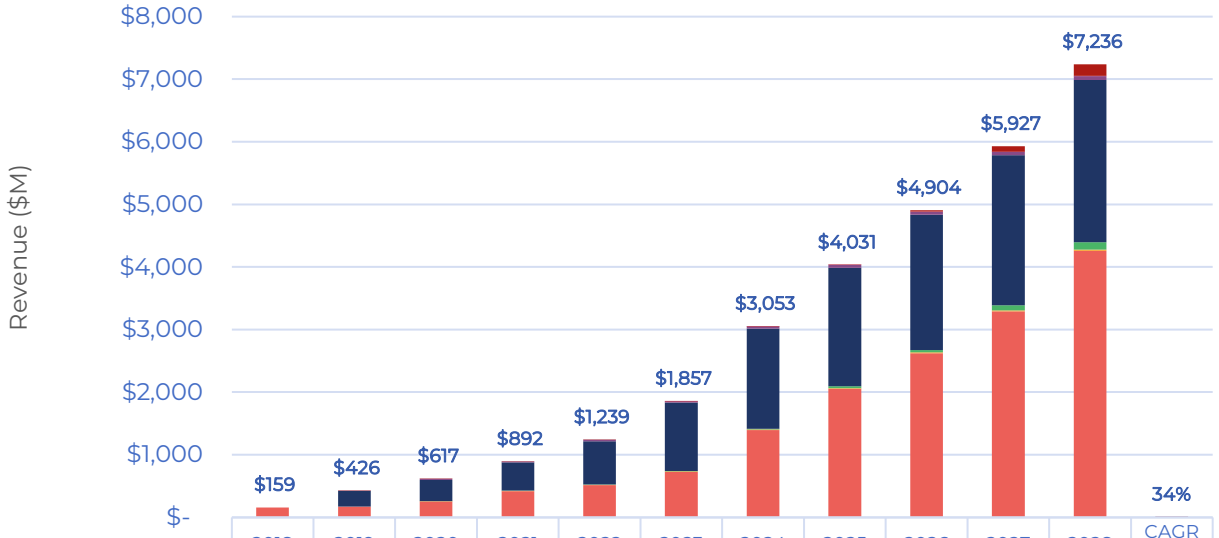
AOC: transceivers with integrated fibers
DAC: copper cables

Each new generation of optical modules is backwards-compatible with the previous-generation technology.

SILICON PHOTONICS MARKET

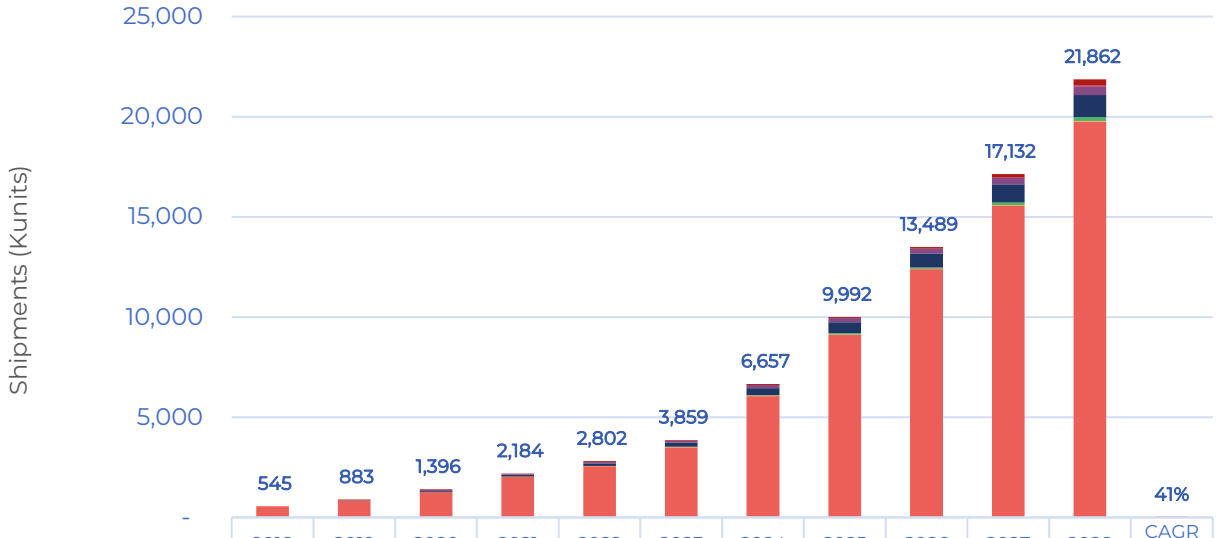
All application **modules**: revenue and shipment forecast (2021 - 2028)

2018-2028 Revenue of SiPho modules - Split by application ($M)



	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	CAGR '22-'28
TOTAL	$159	$426	$617	$892	$1,239	$1,857	$3,053	$4,031	$4,904	$5,927	$7,236	34%
Others	$-	$0	$0	$1	$1	$1	$1	$1	$20	$84	$184	161%
Optical computing	$-	$-	$-	$-	$-	$0	$0	$1	$1	$3	$5	110%
Telecom Wireless	$-	$5	$22	$12	$21	$25	$39	$43	$45	$52	$58	18%
Telecom xWDM	$-	$247	$335	$455	$691	$1,091	$1,600	$1,891	$2,164	$2,400	$2,593	25%
Datacom Optical I/O	$-	$-	$4	$4	$5	$7	$10	$32	$38	$81	$116	68%
Datacom NPO & CPO	$-	$-	$1	$4	$6	$10	$11	$12	$12	$16	$21	21%
Datacom Pluggable	$159	$173	$256	$417	$515	$724	$1,392	$2,051	$2,623	$3,291	$4,259	42%

2018-2028 Shipments of SiPho modules - Split by application (Kunits)



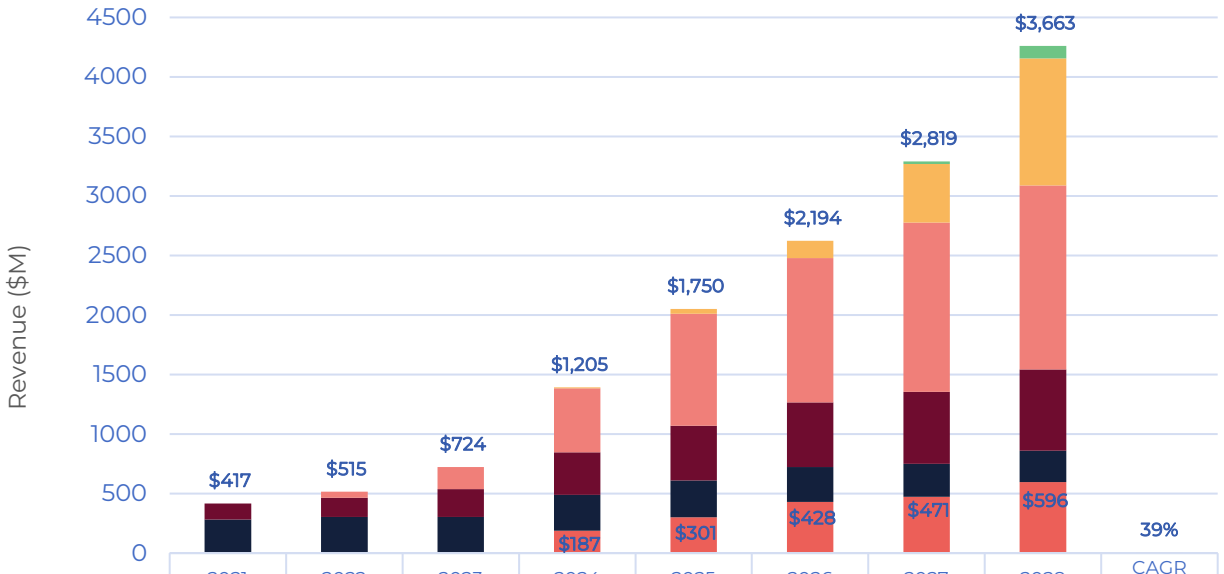
	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	CAGR '22-'28
TOTAL	545	883	1,396	2,184	2,802	3,859	6,657	9,992	13,489	17,132	21,862	41%
Others	-	28	35	37	43	38	43	47	76	162	307	39%
Optical computing	-	-	-	-	-	1	2	6	10	22	42	110%
Telecom Wireless	-	12	54	33	67	89	163	199	236	321	436	37%
Telecom xWDM	-	22	47	77	125	210	360	550	700	915	1,100	44%
Datacom Optical I/O	-	-	1	4	7	10	15	50	61	130	180	72%
Datacom NPO & CPO	-	-	1	4	8	14	18	21	21	28	35	28%
Datacom Pluggable	545	821	1,258	2,029	2,552	3,496	6,057	9,120	12,386	15,554	19,763	41%

- The silicon photonics module market is expected to grow from $1.2B in 2022 to $7.2B in 2028. $CAGR_{2022\text{-}2028}$ = 34%.
- The silicon photonics market is vastly driven by datacom pluggable modules due to demand for capacity of very large cloud service providers (DC hyperscalers).

SILICON PHOTONICS MARKET

DATACOM modules: pluggable optics – revenue and shipment forecast (2021 - 2028)

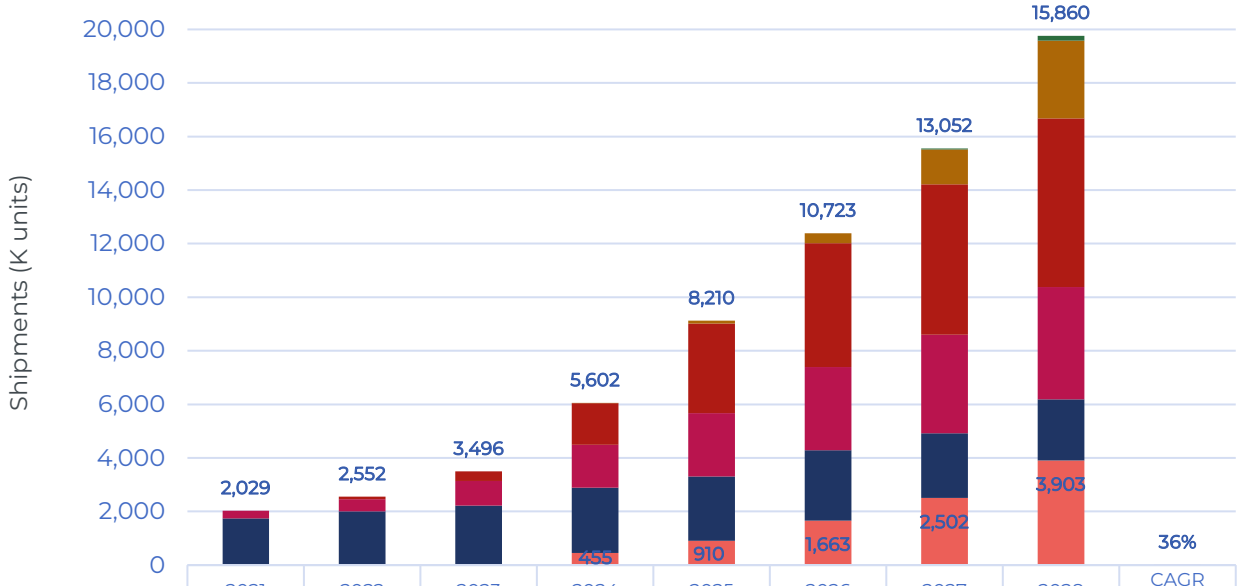
2021-2028 Revenue of SiPho based pluggable Ethernet transceivers ($M)



	2021	2022	2023	2024	2025	2026	2027	2028	CAGR 2022-2028
Total Ethernet	$417	$515	$724	$1,205	$1,750	$2,194	$2,819	$3,663	39%
3.2TbE	$-	$-	$-	$-	$-	$-	$22	$104	
1.6TbE	$-	$-	$-	$7	$41	$145	$492	$1,068	248%
800 GbE	$-	$49	$186	$538	$941	$1,212	$1,423	$1,546	77%
400 GbE	$135	$161	$233	$357	$460	$544	$603	$680	27%
100 GbE	$282	$304	$304	$303	$308	$294	$279	$265	-2%
AOCs				$187	$301	$428	$471	$596	34%

- The silicon photonics datacom module market is expected to grow from $515M in 2022 to $3.7B in 2028. $CAGR_{2022-2028}$ = 39%.
- The silicon photonics datacom module market will be mostly driven by pluggable modules 800GbE and above. The innovations for pluggables will bring power reduction achieved by using TFLN, BTO, organics, or graphene for modulators. These materials are compatible with SOI manufacturing process and will also drive silicon photonics market.

2021-2028 Shipments of SiPho based pluggable Ethernet transceivers (K units)



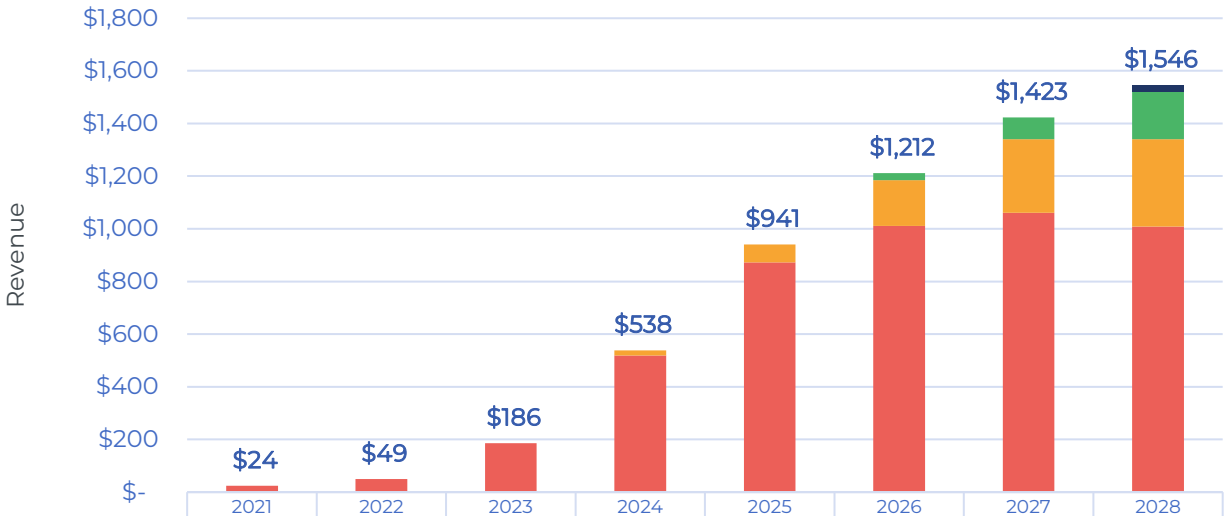
	2021	2022	2023	2024	2025	2026	2027	2028	CAGR 2022-2028
Total Ethernet	2,029	2,552	3,496	5,602	8,210	10,723	13,052	15,860	36%
3.2TbE	0	0	0	0	0	0	38	188	
1.6TbE	0	0	0	14	98	368	1,296	2,898	279%
800 GbE	0	91	360	1,554	3,348	4,625	5,624	6,291	103%
400 GbE	287	453	920	1,603	2,362	3,101	3,681	4,202	45%
100 GbE	1,742	2,008	2,216	2,431	2,402	2,629	2,413	2,281	2%
AOCs	0	0	0	455	910	1,663	2,502	3,903	71%

- The optical modules having silicon PIC have been carefully selected among wide range of ethernet transceiver types for 500m and 2km including AOCs.
- The penetration rate of siph modules for 500m (e.g. DR4, DR8) increases from 25% in 2022 to more than 60% in 2028. In case of siph modules for 2km (e.g. FR4, FR8), the penetration increases from 5% in 2022 to more than 30% in 2028.
- Active Optical Cables will adopt silicon photonics and become serious application for silicon photonics. We assume they will take share of 3%, 5%, 7%, 9% and 12% between 2024 and 2028.

SILICON PHOTONICS MARKET

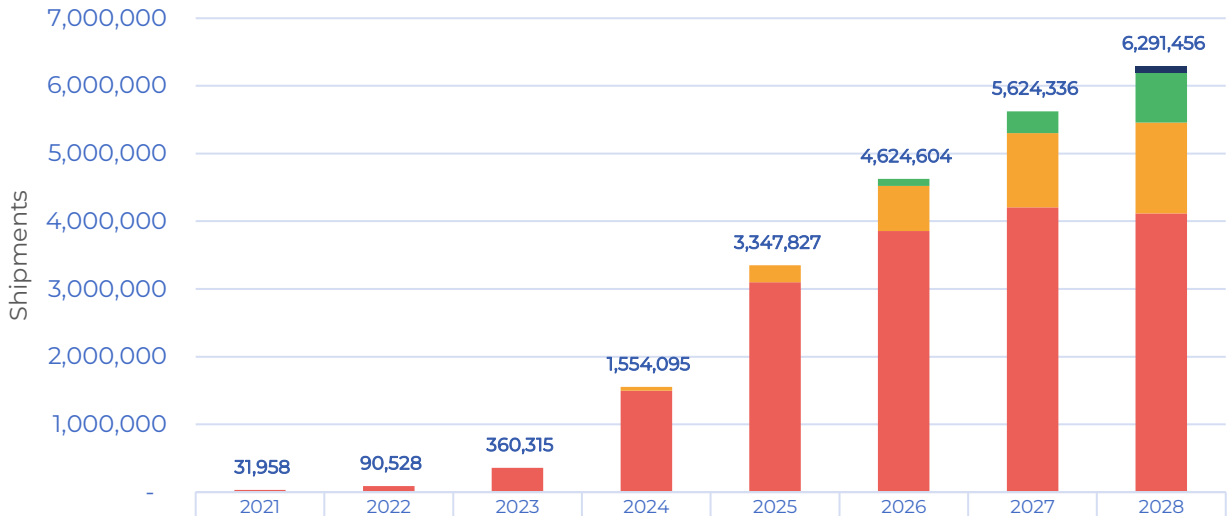
DATACOM modules: 800G pluggables, split by modulator technology

2023 - 2028 revenue of 800G ethernet (SiPho: 500m - 2km) – split by modulator ($M)



	2021	2022	2023	2024	2025	2026	2027	2028
Total	$24	$49	$186	$538	$941	$1,212	$1,423	$1,546
SiPho (Organic)	$-	$-	$-	$-	$-	$-	$-	$24
SiPho (BTO)	$-	$-	$-	$-	$-	$28	$83	$182
SiPho (TFLN)	$-	$-	$-	$19	$68	$174	$279	$332
SiPho (Si MRM)	$24	$49	$186	$519	$873	$1,011	$1,061	$1,008

2023 - 2028 shipments of 800G ethernet (SiPho: 500m - 2km) – split by modulator (units)



	2021	2022	2023	2024	2025	2026	2027	2028
Total	31,958	90,528	360,315	1,554,095	3,347,827	4,624,604	5,624,336	6,291,456
SiPho (Organic)	-	-	-	-	-	-	-	98,768
SiPho (BTO)	-	-	-	-	-	103,372	324,061	732,963
SiPho (TFLN)	-	-	-	55,115	246,553	664,952	1,096,675	1,342,652
SiPho (Si MRM)	31,958	90,528	360,315	1,498,980	3,101,273	3,856,280	4,203,600	4,117,071

- The silicon photonics datacom module market will be mostly driven by pluggable modules 800GbE and above. The innovations for pluggables will bring power reduction achieved by using TFLN, BTO and organics for modulators. These materials are compatible with SOI manufacturing process and will also drive silicon photonics market. The forecasts show different time to market for TFLN, BTO and organics technologies.

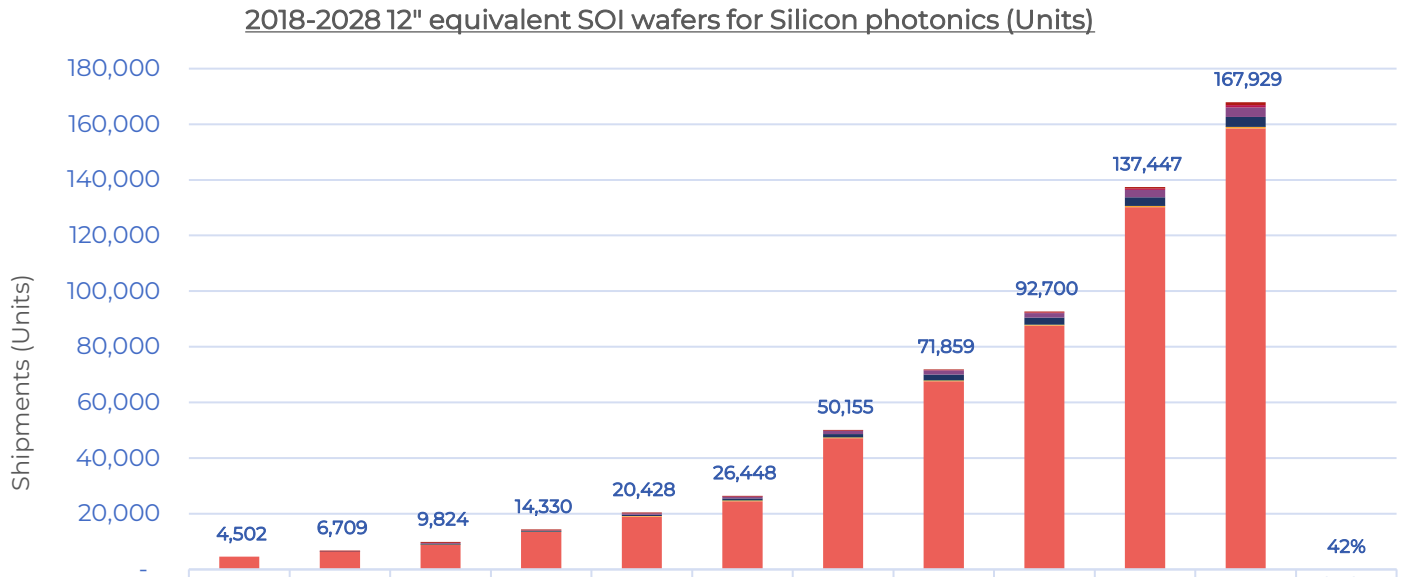
SILICON PHOTONICS MARKET

All applications: 12” equivalent SOI wafers forecast (2021 - 2028) for silicon photonics

The market forecast analyses in 2023 revealed a discrepancy in data (shipments, revenue, SOI wafers). The reasons have been explained at the beginning of this chapter.

Likely real silicon photonics market is low. However, SOI wafer suppliers report a notable higher shipments of wafers to the silicon photonics foundries than we calculated from the real market volume. The yield was assumed as high as 80% in the report edition v2022.

We believe the manufacturing yield of PICs is significantly lower (~18%) as well as imperceptible volume of PIC dies have been used for experimental research in the R&D centers and universities which is invisible in the real market.

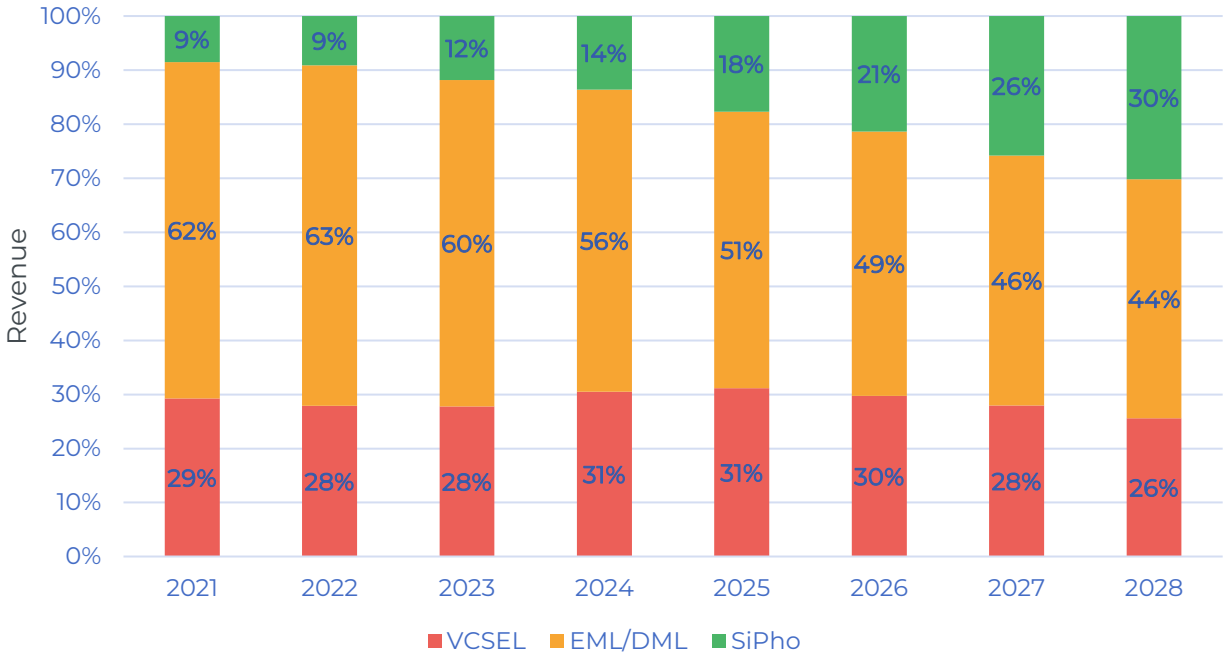


	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	CAGR '22-'28
TOTAL	4,502	6,709	9,824	14,330	20,428	26,448	50,155	71,859	92,700	137,447	167,929	42%
Others	-	254	304	300	315	264	256	268	362	642	1,084	23%
Photonic computing	-	-	-	-	-	25	52	113	192	411	743	97%
Telecom Wireless	-	93	381	216	500	625	1,267	1,478	1,669	2,683	3,495	38%
Telecom xWDM	-	105	209	320	472	747	1,121	2,039	2,477	3,097	3,568	40%
Datacom Optical I/O	-	-	0	3	5	6	8	13	15	15	20	28%
Datacom NPO & CPO	-	-	24	91	165	272	297	332	329	420	506	21%
Datacom Pluggable	4,502	6,256	8,906	13,401	18,972	24,509	47,154	67,617	87,656	130,180	158,512	42%

SILICON PHOTONICS MARKET

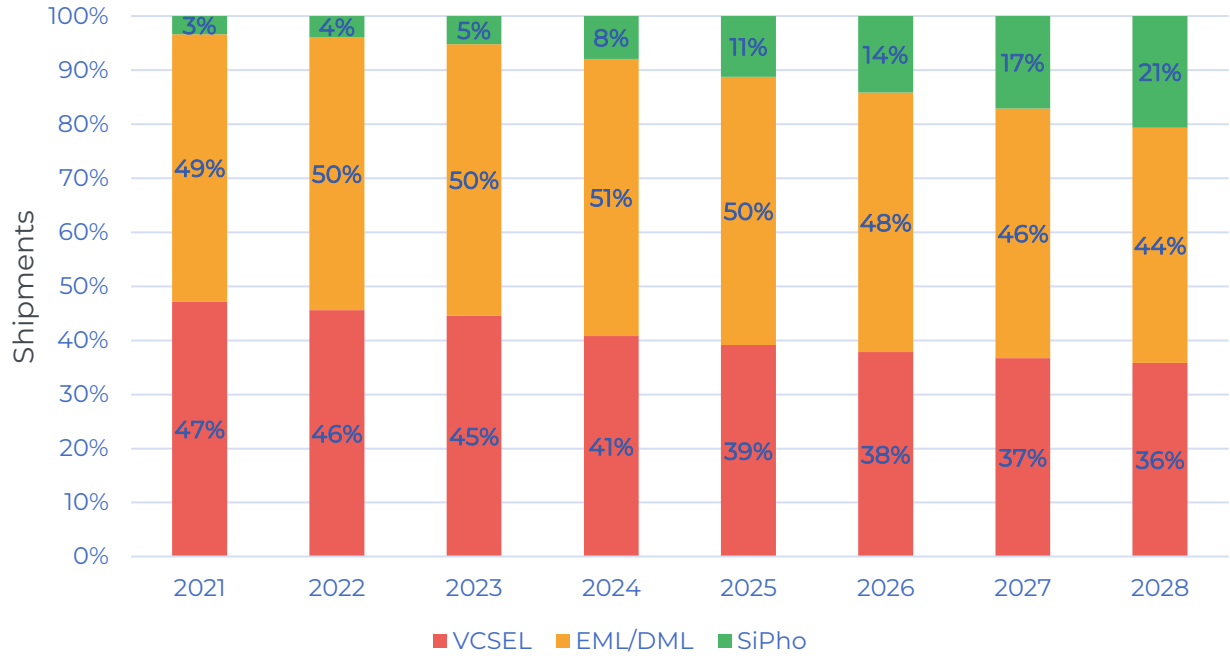
DATACOM modules: ethernet – penetration rate of technology platforms forecast (2021 - 2028)

Penetration rate of laser technologies – revenue



- The market revenue revenue share of silicon photonics ethernet transceivers was estimated 9% in 2022 and is expected to increase to 30% in 2028 of total revenue of the ethernet transceivers.

Penetration rate of laser technologies – shipments

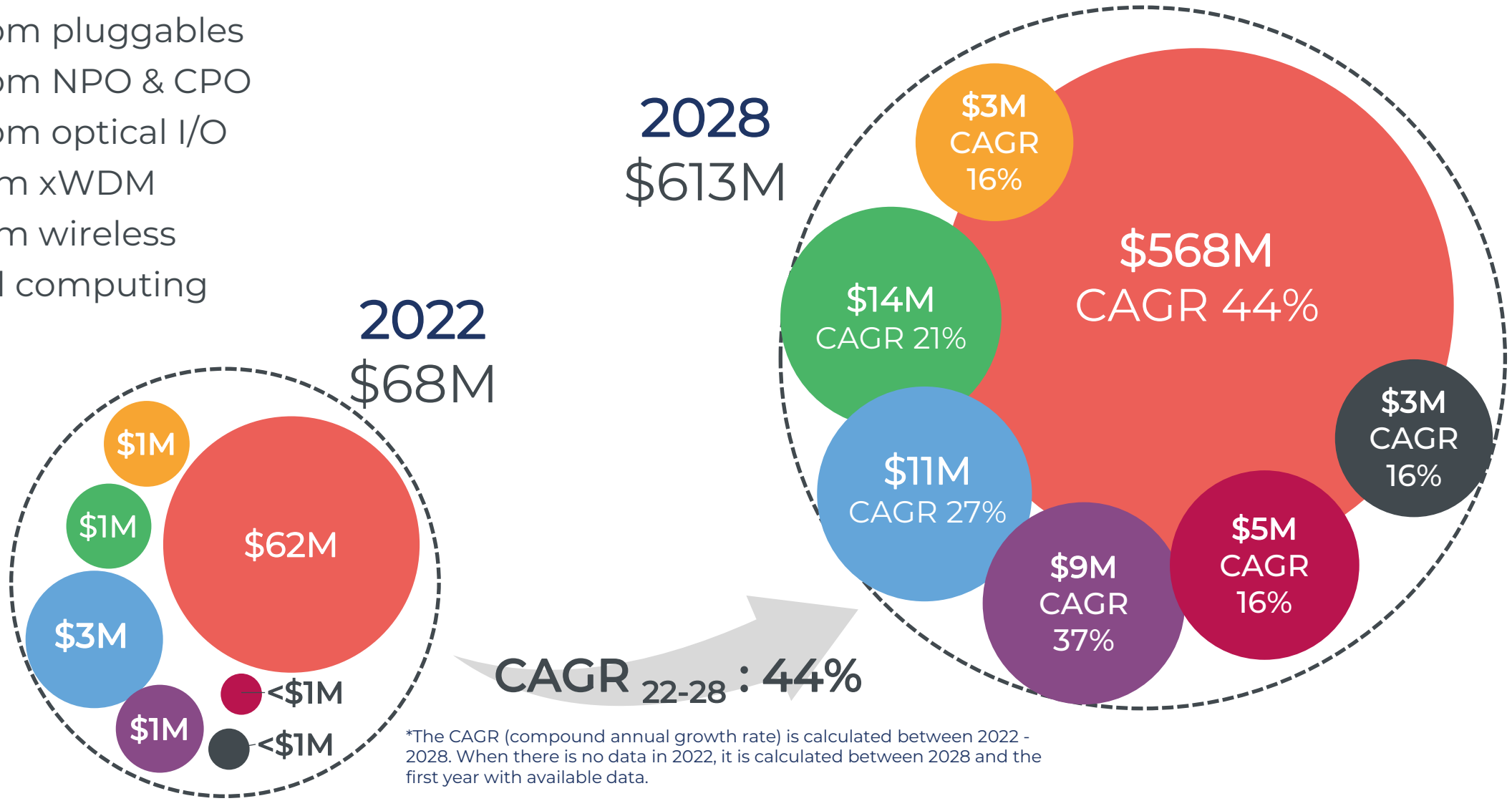


- The penetration of silicon photonics into ethernet transceivers will be increasing from 4% to 21% between 2022 and 2028.

SILICON PHOTONICS MARKET

Silicon photonic PICs (dies) revenue growth forecast: by application (2022 vs. 2028)

- Datacom pluggables
- Datacom NPO & CPO
- Datacom optical I/O
- Telecom xWDM
- Telecom wireless
- Optical computing
- Others



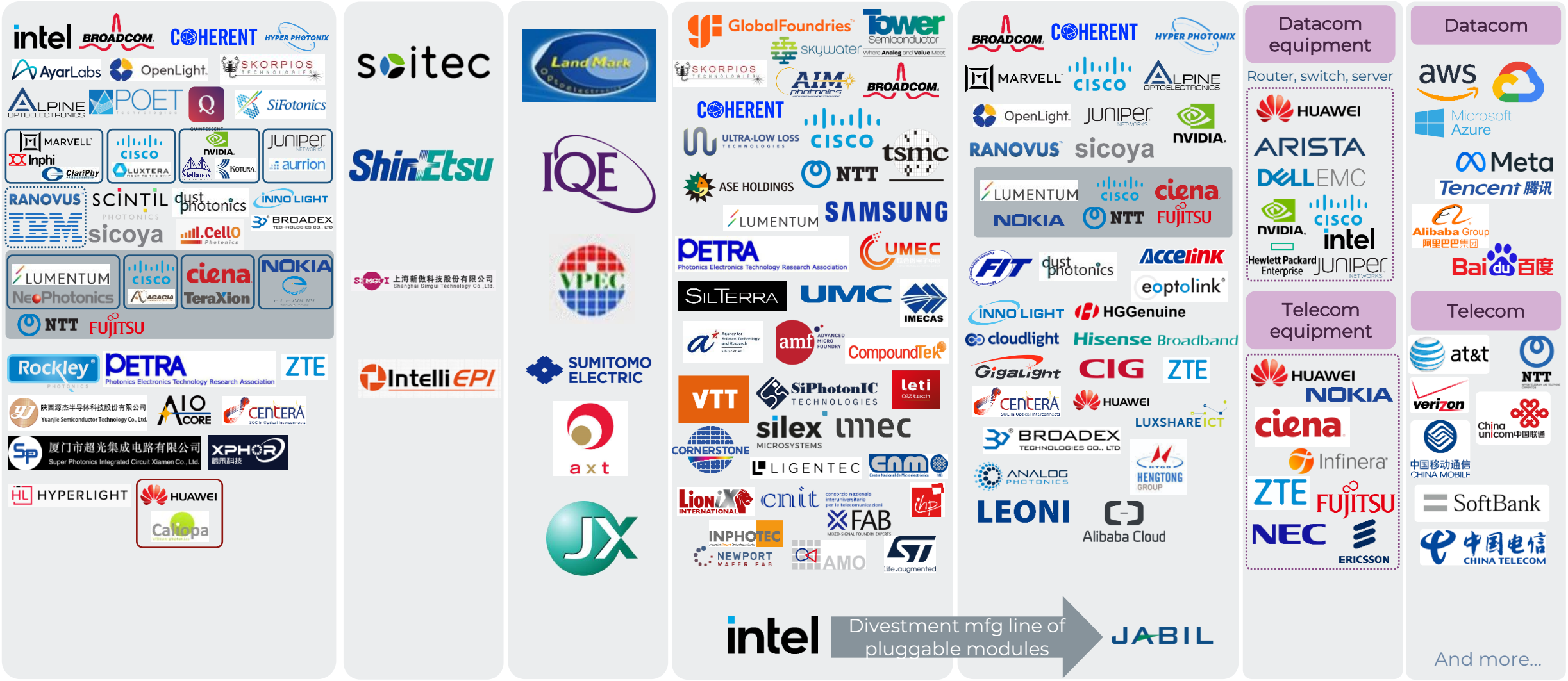
*The CAGR (compound annual growth rate) is calculated between 2022 - 2028. When there is no data in 2022, it is calculated between 2028 and the first year with available data.

PIC: photonics integrated circuit
NPO: near packaged optics
CPO: co-packaged optics

I/O: input/output
xWDM: wavelength division multiplexing

SILICON PHOTONICS VALUE CHAIN FOR OPTICAL COMMUNICATION

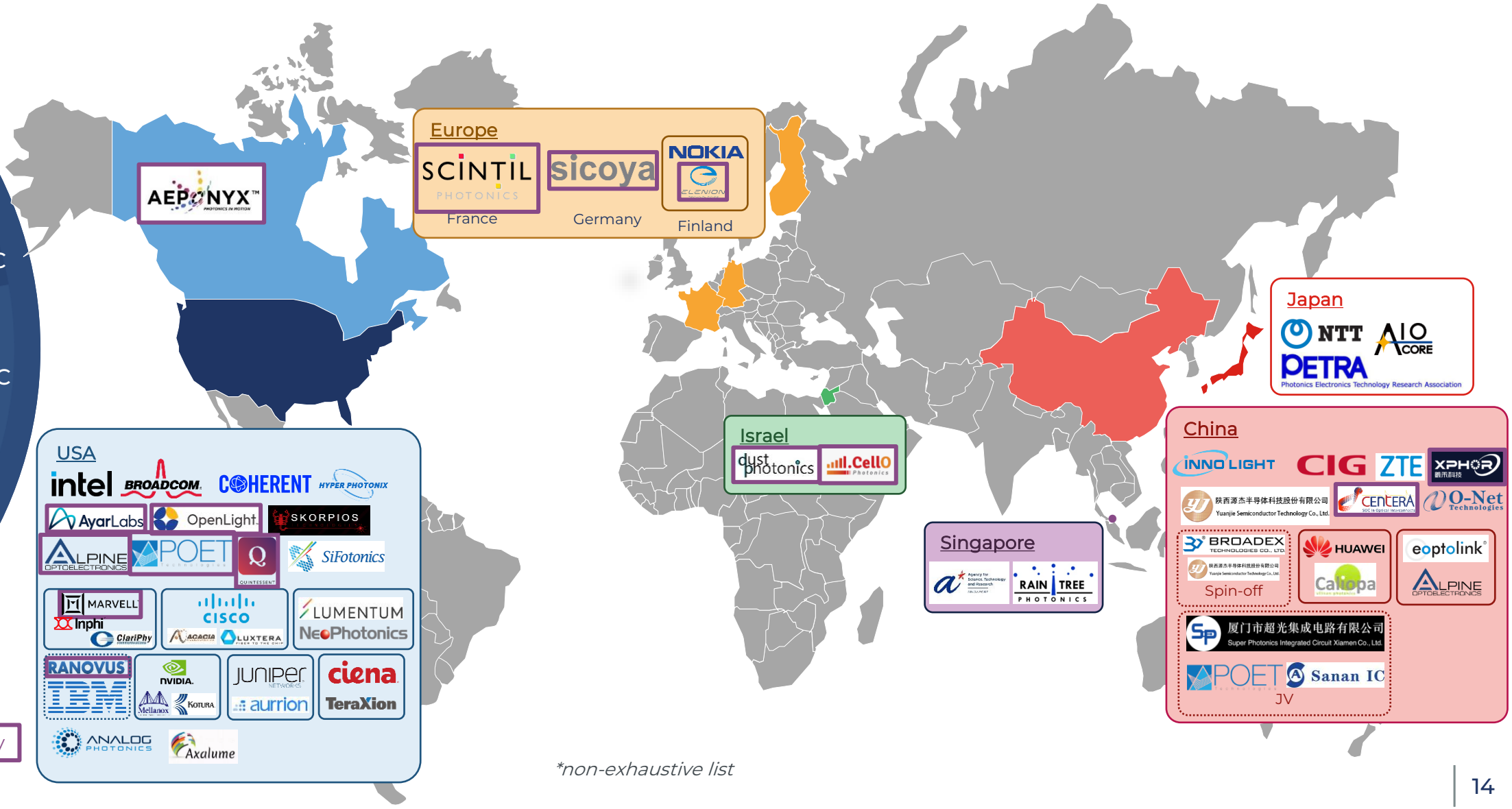
PIC Design | SOI substrate | Epi-wafer suppliers | Foundry and fabs | Transceiver integrator | Equipment | Operators (customers)



SILICON PHOTONICS PLAYERS

Networking: PIC designers and vertically integrated transceiver suppliers

Some silicon PIC designers have internal capabilities to manufacture PIC or even deliver module products.



M&A

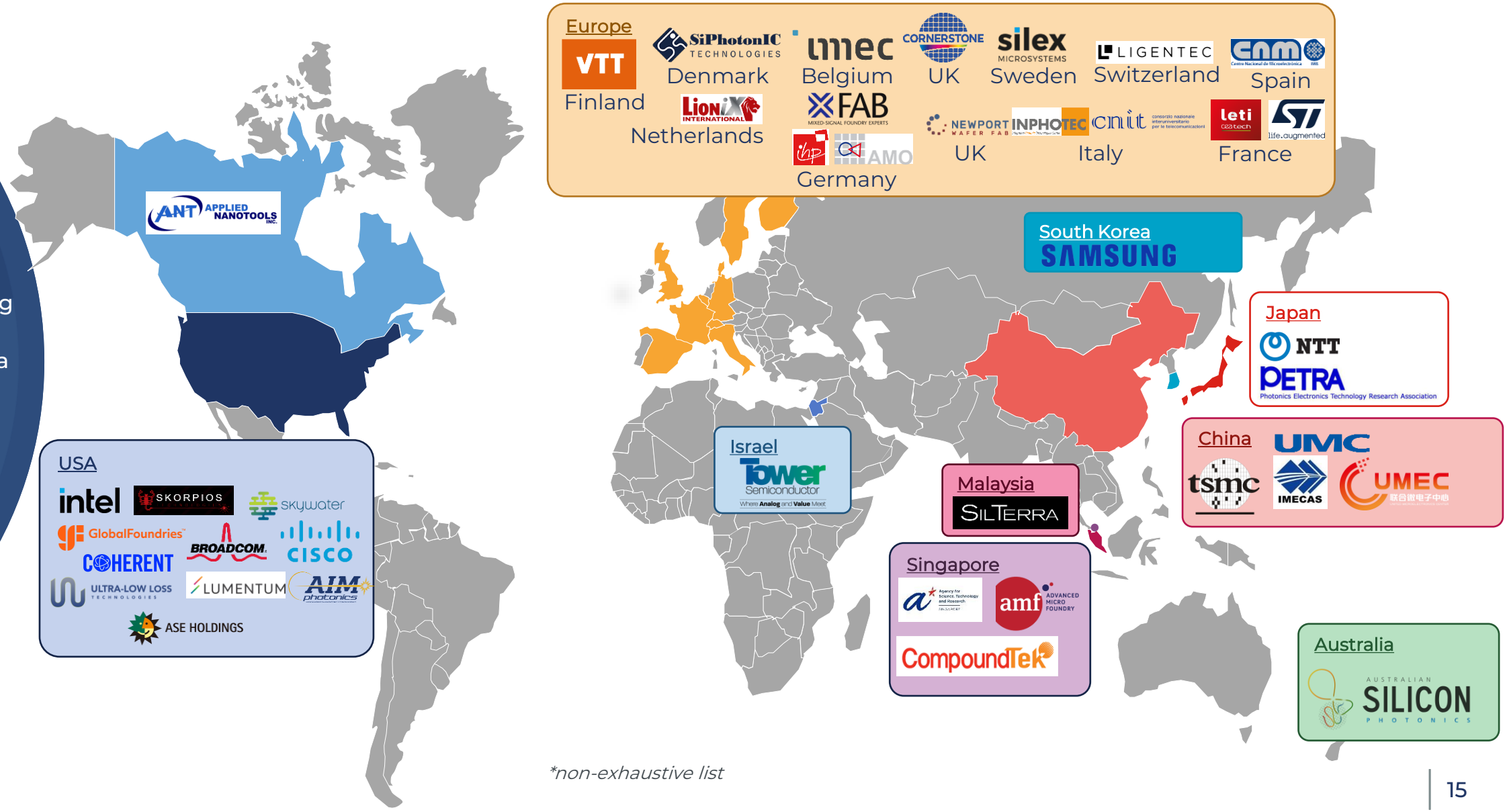
Design only

*non-exhaustive list

SILICON PHOTONICS PLAYERS

Foundries and fabs

Silicon PIC manufacturing processes have been developing mostly in small R&D fabs. Only a few IDMs or pure-play foundries produce PIC in HVM for optical interconnects.

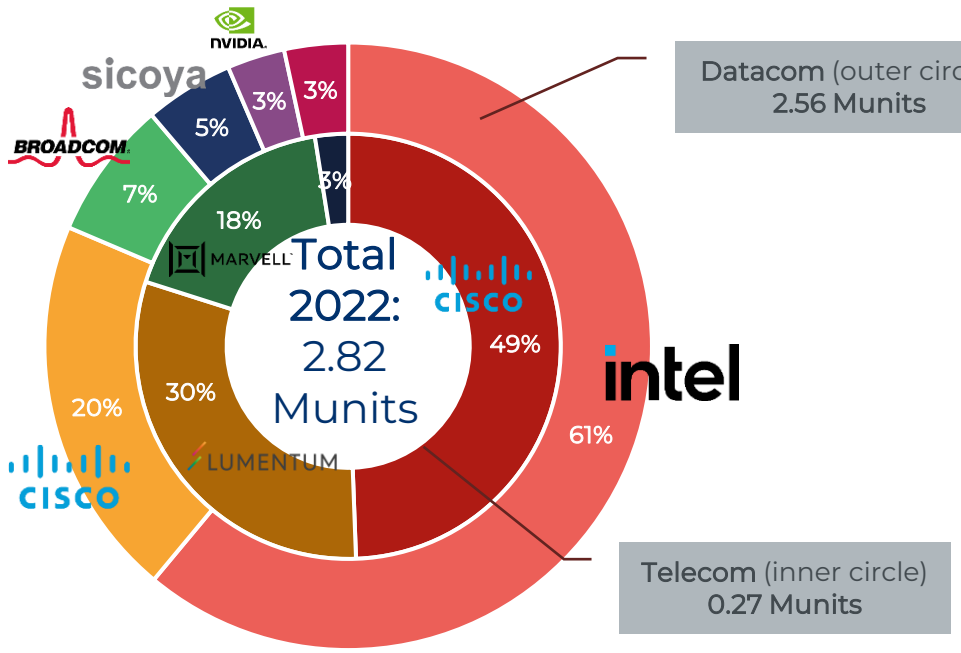


*non-exhaustive list

MARKET SHARE & SUPPLY CHAIN

Market share 2022: datacom & telecom **shipments**

In shipments, silicon photonics-based transceivers for intra-DC, DCI, and wireless is estimated to be **2.8 million units** in 2022.



Datacom (Kunits)	
Intel	1 560,00
Cisco (Luxtera)	520,67
Broadcom	188,99
Sicoya	121,49
Nvidia (Mellanox)	78,59
Others datacom	86,78
Total	2 556,51

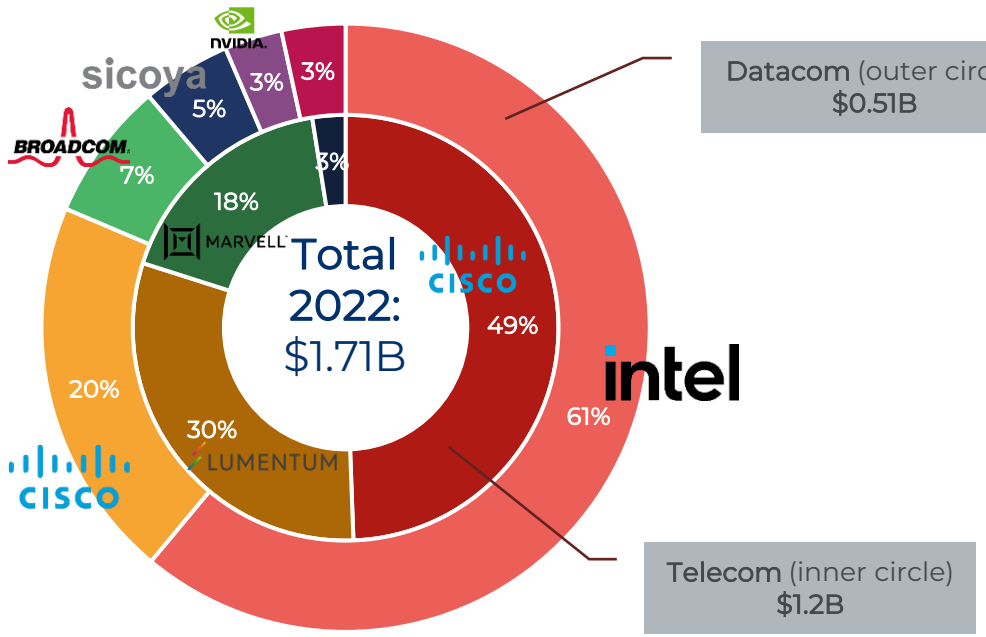
Telecom (Kunits)	
Cisco (Acacia)	131.19
Lumentum (Neophotonics)	80.98
Marvell (Inphi)	46.67
Others telecom	6.67
Total	265.50

- Intel
- Cisco (Luxtera)
- Broadcom
- Sicoya
- Nvidia (Mellanox)
- Others Datacom
- Cisco (Acacia)
- Lumentum (Neophotonics)
- Marvell (Inphi)
- Others Telecom

MARKET SHARE & SUPPLY CHAIN

Market share 2022: datacom & telecom **revenue**

In value, silicon photonics-based transceivers for intra-DC, DCI, and wireless is estimated to be **$1.71 billion** in 2022.



Datacom ($M)	
Intel	$314.60
Cisco (Luxtera)	$105.00
Broadcom	$38.11
Sicoya	$24.50
Nvidia (Mellanox)	$15.85
Others datacom	$17.50
Total	$515.56

Telecom ($M)	
Cisco (Acacia)	$590
Lumentum (Neophotonics)	$364
Marvell (Inphi)	$210
Others telecom	$30
Total	$1 195

- Intel
- Cisco (Luxtera)
- Broadcom
- Sicoya
- Nvidia (Mellanox)
- Others Datacom
- Cisco (Acacia)
- Lumentum (Neophotonics)
- Marvell (Inphi)
- Others Telecom

TECHNOLOGY TRENDS

Silicon photonics roadmap: integration

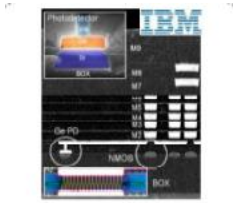
III-V | TFLN | BTO | SiN | Organics | Graphene | SOI

The integration of various electro-refractive and **electro-absorptive materials** open up additional routes toward new silicon photonics applications.

Co-Packaged optics assembly | Quantum Information processing | Quantum Key Distribution (QKD) | Micro-comb laser | Photonic Neural Network | Solid-state LiDAR on-a-chip system | On-chip spectroscopic gas sensor

Bookham released the first silicon photonics product.

The first silicon photonics VOA by Kotura

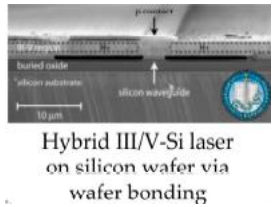


4×25Gbps single-die WDM transceiver

Intel product: monolithic Ge/Si APD with 340GHz gain BW

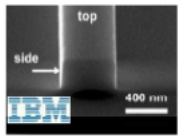
4×12.5 Gbps silicon photonics transceiver

On-chip optical interconnection


Hybrid III/V-Si laser on silicon wafer via wafer bonding

Intel product: 40Gbps optical modulator

LUXTERA FIBER TO THE CHIP
4×25 Gbps QSFP optical module



Low loss CMOS-compatible silicon strip waveguides

Courtesy of Intel, IBM, Berkeley, Luxtera

Comb lasers for DWDM

QD lasers

QW lasers

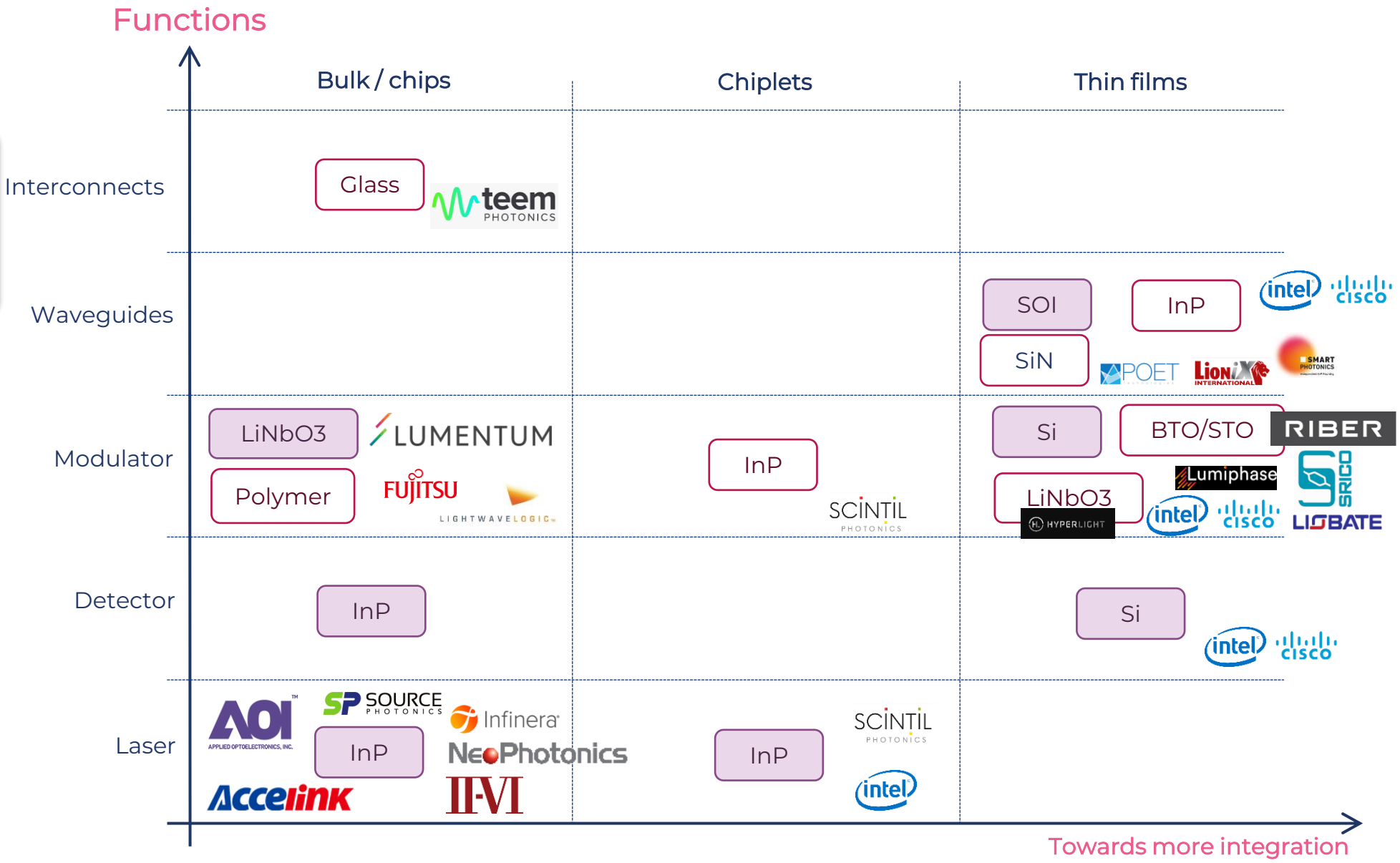
Ultra low-loss waveguide	Individual devices	Hybrid integration	Heterogeneous integration	Monolithic integration	Large-scale multi-functionalization
1992	2005	2010	2015	2020	2030
	SSI era: 1-10 components on a PIC	MSI era: 10-500 components on a PIC	LSI era: 500-1000 components on a PIC	VLSI era: >1000 components on a PIC	
	SiPho: challenger technology	*Usher in the commercial success*	*SiPho: incumbent technology*	*Prototypes demonstrated*	

PICS AGGREGATE DIFFERENT MATERIALS

Many developments for new modulation materials. Bulk LNO is only used in telecom.

Legend: R&D, Prod.

Player logos are NOT exhaustive – especially for InP players, which are numerous.



SILICON PHOTONICS FOR PROCESSING

Market trends and applications

Silicon photonics is pursuing three main applications in computing: off-chip optical interconnects, photonic computing, and quantum computing.

Off-chip optical interconnects

The power needed for off-chip communication is increasing over time because of increased computing power. One solution to overcome this issue is to use optical interconnects for off-chip communication, the main application being high-performance computing (HPC). The use of off-chip optical interconnects is also motivated by a new datacenter architecture, called “disaggregated datacenter”.

- Examples of players: AyarLabs, Nvidia, HPE

Photonic processing

Using arrays of Mach Zehnder modulators, photonic processing has the ability to perform calculations for machine learning (ML). Since the computation is analog, it is much faster than digital computations done by electronic computers. Photonic processing has, therefore, a high potential in high-performance computing (HPC).

- Examples of players: iPronics, QUIX, Lightelligence, Celestial AI, Lightmatter, NLM, AIO Core, Luminous

Quantum computing

- Quantum photonics
- Atom manipulation
- Photon Qubits

- Examples of players: PsIQ, IonQ, Xanadu

CONCLUSION

Silicon photonics 2022: the success story continues

The Si photonics platform's maturity and rapidly-developing ecosystems fuel market-share growth in datacom and pull into its vicinity new developments in multiple markets.

- Silicon photonics is now a well-established technology and market, particularly for ethernet pluggable optical transceivers.
  - In 2022, more than 2.5 million silicon photonics-based pluggable transceivers were shipped, which accounts for 4% of market share. However, in value in 2022, we expect more than 20% market share in shipments and 30% in market revenue.
  - Intel and Cisco remain market leaders. Other players have announced new silicon photonics products, so it is expected they will take share from these two leaders in the next years.
- More silicon photonics applications are coming to datacom, with CPO or optical interconnect I/O being commercialized in 2023 or 2025 by companies such as Broadcom and AyarLabs.
  - The CPO market will rather small until 2029 - 2031, when 200T switch bandwidth will require a new architecture.
- Intel announced Si photonic LiDAR for 2025/26 based on FMCW, while we assume the availability around 2027.
- In 2021, Rockley Photonics announced plans for biosensors in smartwatches using silicon photonics, but market commercialization is still uncertain.
- Photonic computing could also be an important application for silicon photonics.

THANK YOU

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	Silicon Photonics 2023	Co-Packaged Optics 2023	Optical Transceivers 2023
Wafer forecast	Included	Not included	Not included
Die forecast	Included (detailed)	Not included	Not included
Module forecast			
Datacom pluggable transceivers	Included	Not included	Included (detailed)
Optical engines	Included	Included (detailed)	Not included
In-package optical I/O	Included	Included (detailed)	Not included
Telecom pluggable transceivers	Included	Not included	Included (detailed)
Market share	Included	Not included (industry is being formed)	Included
Players and supply chain	Included	Included	Included
Technologies analysis	Laser integration, packaging, testing, material-level	Modules and component-level (laser, photodiode)	Modules and component-level (laser, photodiode)