GLOBAL TECH

Optical Networking

The next mega trend in AI infrastructure

Networking unlocks computing capability for single AI chips, connecting multiple chips (working together), enabling seamless data exchange and low latency, and driving AI to the next level. Along with an AI infrastructure ramp-up and rising computing power per rack, we expect all configurations to enjoy strong growth ahead, opening a further 9x TAM unlock to US$154bn. Specifically, we discover: (1) 16x / 45x dollar content increase in scale out / scale up, (2) 13x larger TAM for optics expanding from scale out to scale up, (3) 10x larger value market for pluggable optical modules in scale out from 2H25 AI server model to 2H27 AI server model. In this report, we analyze: (1) dollar content across different configurations, (2) Scale-out and Scale-up market opportunities, (3) Component contributions across copper cables, pluggable optical modules, CPO, and PCB midplanes, and (4) EPS upside across the supply chain. We remain bullish on our Optical and PCB coverage, including Buy rated: Innolight, Eoptolink, TFC Optical, Landmark, VPEC, Sumitomo, Mitsubishi, Furukawa, Victory Giant (on CL), WUS, EMC and Shengyi. We expect these companies to see strong growth into 2028E on AI servers ramp up, specification upgrade, and usage expansion.

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Table of Contents

Networking is the next frontier in AI infrastructure, poised to enhance computing capability through seamless data exchange and low latency. While an investor concern is on networking configuration replacing another, we expect all configuration will enjoy strong growth. Specifically:

Scale out: Adding more equipment and connecting them through switching technologies, a widely used way of network expansion. Nowadays, AI clusters support scale out connections of 100k+ GPUs.

Scale up: Adding more GPUs and computing resources within the same piece of equipment, typically within the same server rack. Nowadays there are scale-up expansions that connect across racks, or the so-called supernodes, where the networking speed across racks are optimized to close to the connections within the same rack.

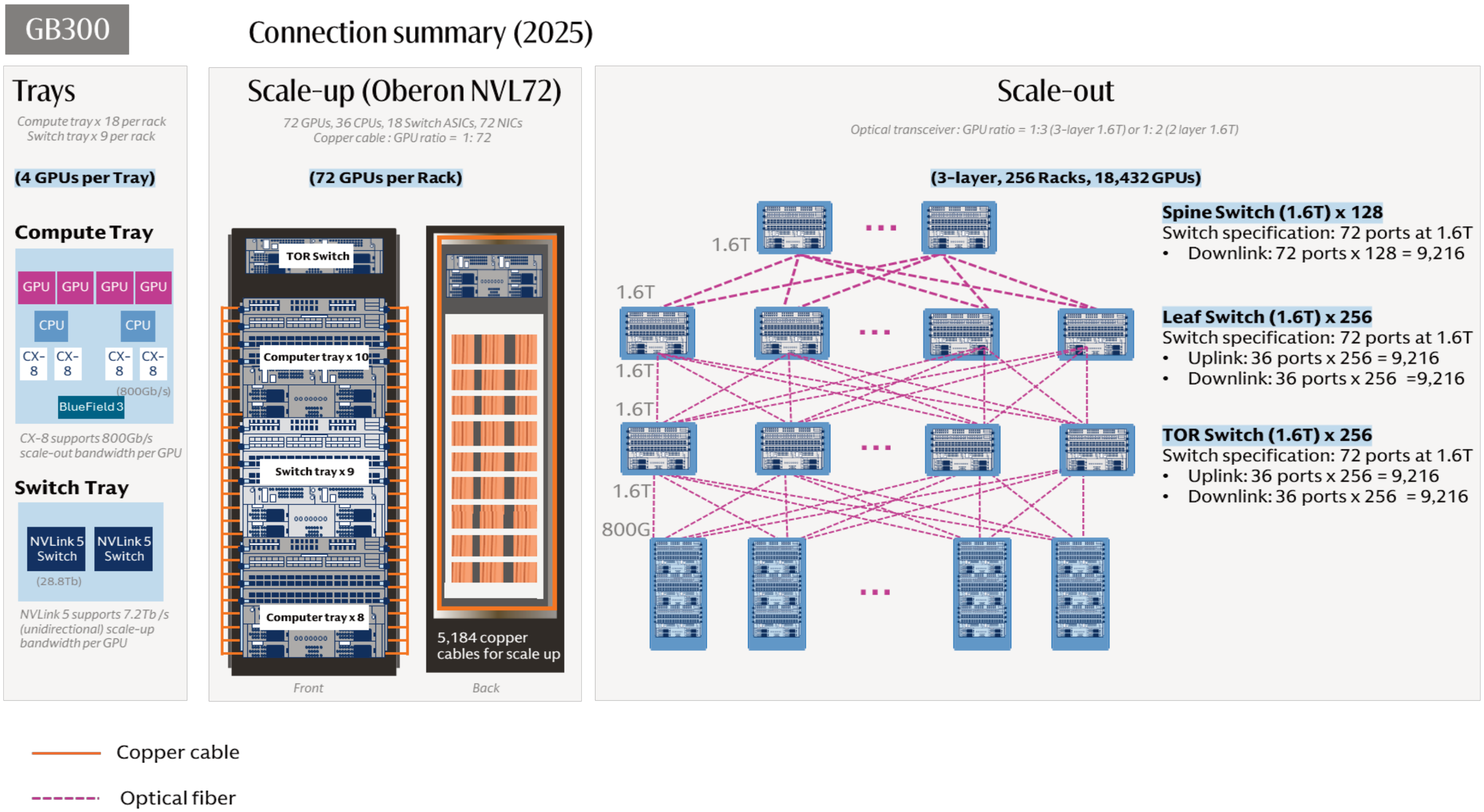
- **Dollar content increase by 16x / 45x in Scale Out / Scale Up** per computing unit from GB300 NVL72 (per computing unit means 72 GPUs per rack to reach NVL72) to Rubin Ultra NVL576 (per computing unit means 72 GPUs per rack, and 8 racks together to reach NVL576), with opportunities across pluggable optical modules, optical engines in CPO, copper cables, and PCB midplanes.
- **A 13x larger addressable market** for optical modules / optical engines expanding from scale out (e.g. GB300 NVL72) to scale up (e.g. Rubin Ultra NVL576 level 2 scale up via CPO) per computing unit.
- **A 10x larger value market for pluggable optical modules** in scale out per computing unit from GB300 NVL72 to Rubin Ultra NVL576, even with a 29% CPO penetration rate. The numbers of pluggable optical module (1.6T equivalent) per computing unit would increase from 216 units in GB300 NVL72 to 2.5k units in Rubin Ultra NVL576.

We expect the aggregate dollar content per computing unit across scale up and scale out to increase by 29x from US$315k in GB300 NVL72 to US$9.4bn in Rubin Ultra NVL576, and assuming the numbers of racks through the full product cycle are 48k racks for GB300 NVL72, and 16.5k computing units for Rubin Ultra NVL576, the aggregate value TAM across scale up and scale out would increase by 9x from **US$15bn** in GB300 NVL72 (mainly in **2026**) to **US$154bn** in Rubin Ultra NVL576 (mainly in **2028**). Among the US$154bn value TAM, 69% goes to scale up, or US$106bn, and **CPO** contributes **US$91bn**, or 59% of the US$154bn value TAM, assuming CPO at 29% penetration rate in scale out.

We expect significant **EPS upside** for key beneficiaries across **Optical modules and engines** (CPO/NPO adoption and optical module upgrades)**, CW lasers and EMLs** (CPO/NPO adoption and optical module upgrades)**, and PCB/CCL manufacturers** (PCB midplane adoption). We remain bullish on our optical and PCB coverage, including our Buy rating coverage: **Innolight**, **Eoptolink, TFC Optical, Landmark, VPEC, Sumitomo, Mitsubishi, Furukawa, Victory Giant (on CL), WUS, EMC and Shengyi**. We expect these companies to see strong growth into 2028 on AI servers ramp up, specification upgrade, and usage expansion. The migration would be firstly seen in leading global CSPs (cloud services providers), followed by China CSPs, driving sustainable strong growth in the networking supply chain over the coming five years, in our view.

(1) Blackwell network in details

Exhibit 1: Nvidia GB300 AI rack network summary (2025)

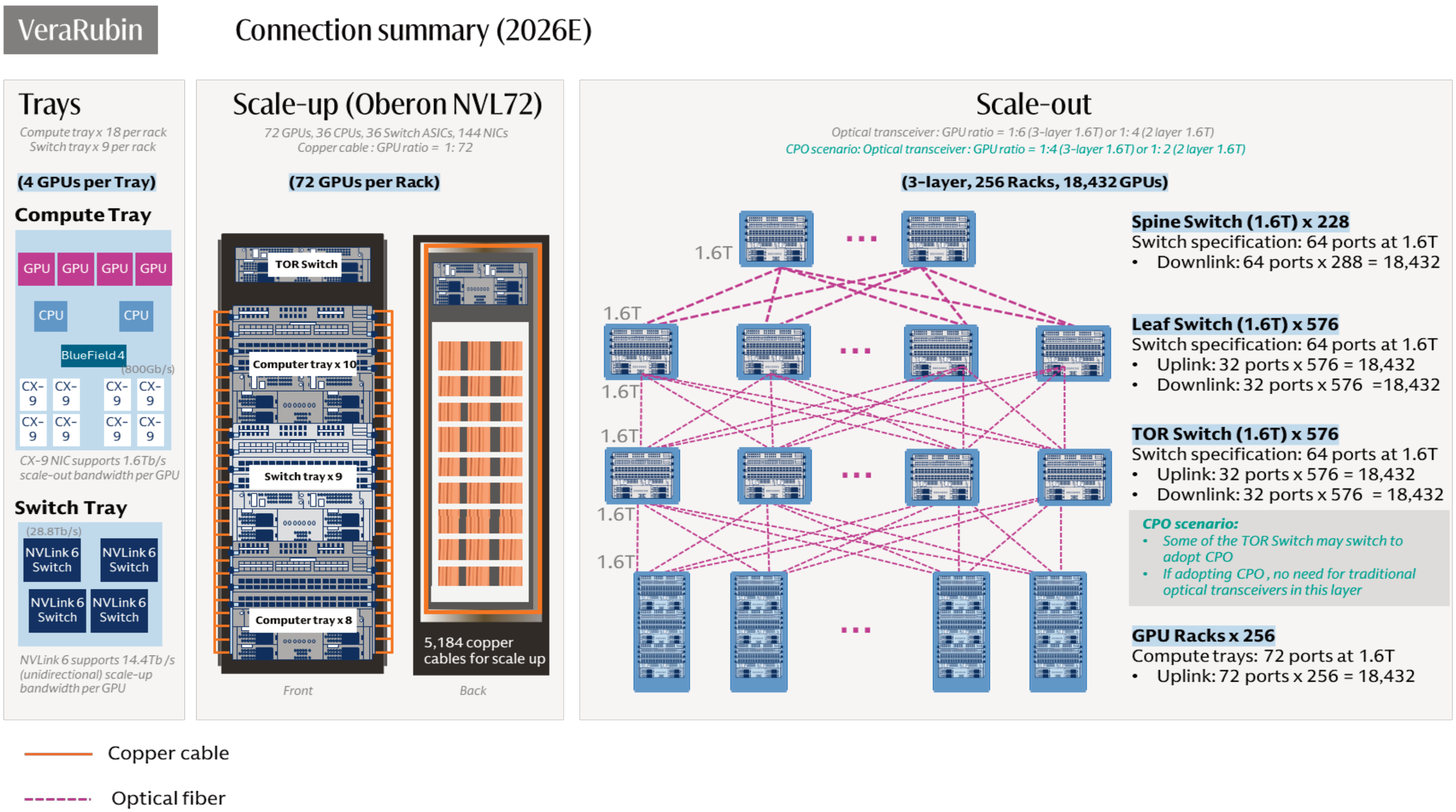


Scale out switch spec refer to Quantum-X800.

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

(2) Rubin network in details

Exhibit 2: Nvidia Vera Rubin AI rack network summary (2026E)

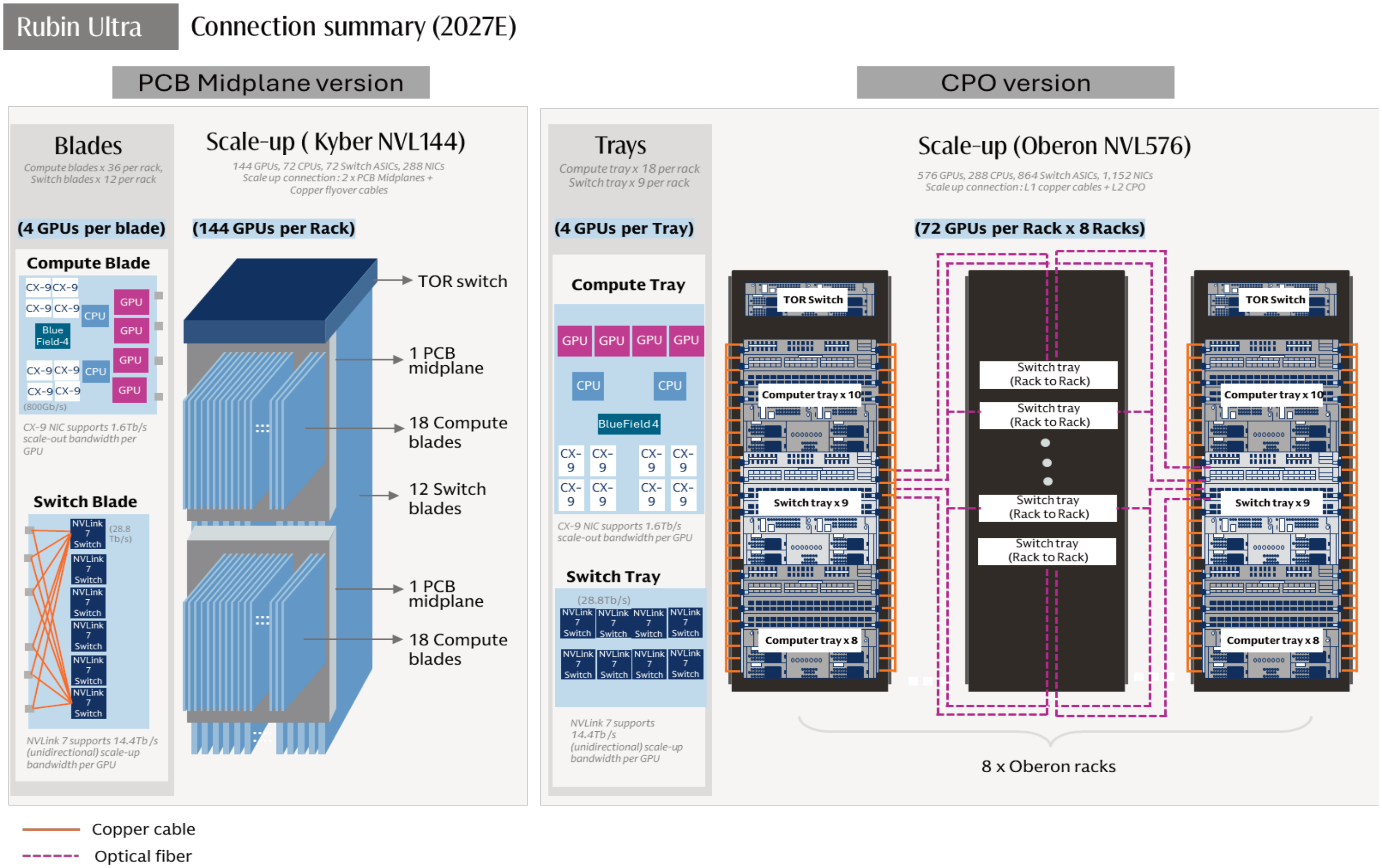


Scale out switch spec refer to Spectrum-6. The data in this exhibit is inferred by GS based on technology roadmap of Nvidia and our supply chain check.

Source: Company data, Goldman Sachs Global Investment Research

(3) Rubin Ultra network in details

Exhibit 3: Nvidia Rubin Ultra AI rack network summary (2027E)



The data in this exhibit is inferred by GS based on technology roadmap of Nvidia and our supply chain check.

Source: Company data, Goldman Sachs Global Investment Research

(4) Optical networking supply chain

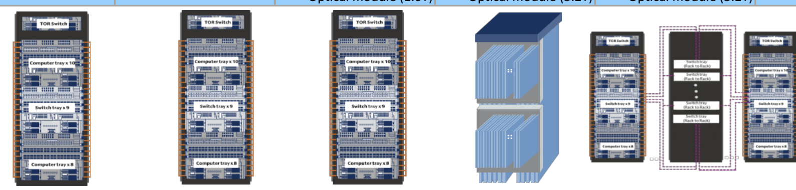
Exhibit 4: Optical supply chain

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

(5) Scale up / Scale out TAM and EPS implications

Exhibit 5: Spec Table: We outline four possible rack structure for the upcoming GPU platforms (GSe)
The connection architecture and specifications below are based on Nvidia technology roadmap, supply chain check and our inference based on the networking connections

Connection assumptions		Vera Rubin Spec A	Vera Rubin Spec B	Rubin Ultra Spec A	Rubin Ultra Spec B	
Model	**GB300 NVL72**	**Vera Rubin NVL 72**	**Vera Rubin NVL 72 (25% CPO scale out)**	**Rubin Ultra NVL 144 (29% CPO scale out)**	**Rubin Ultra NVL 576 (29% CPO scale out)**	**Remarks**
Shipment period	2H25-2026	2H26-2027	2H26-2027	2H27-2028	2H27-2028	
Scale up	Copper cable	Copper cable	Copper cable	PCB Midplane	Copper cable + CPO	
Scale out	Optical modules (1.6T)	Optical modules (1.6T)	CPO TOR Switch (1.6T) + Optical module (1.6T)	CPO TOR Switch (3.2T) + Optical module (3.2T)	CPO TOR Switch (3.2T) + Optical module (3.2T)	



	GB300 NVL72	Vera Rubin NVL 72	Vera Rubin NVL 72 (25% CPO scale out)	Rubin Ultra NVL 144 (29% CPO scale out)	Rubin Ultra NVL 576 (29% CPO scale out)	Remarks
# of GPU package	72	72	72	144	72	* For Rubin Ultra NVL576, we show per rack
# of NV Switch ASIC	18	36	36	72	108	data in the table, despite it's a 8-rack scale up
# of NIC	72	144	144	288	144	system
Scale up						
Scale up Bandwidth (unidirectional, Tb/s)	**518**	**1,037**	**1,037**	**2,074**	**2,074**	
Total Switching Capacity (Tb/s)	**1,037**	**2,074**	**2,074**	**4,147**	**6,221**	
Copper cable backplane bandwidth (Tb/s)	518	1,037	1,037	-	2,074	
Notes	*100% copper cable*	*100% copper cable*	*100% copper cable*	-	*L1 scale up within rack*	
# of copper cables (units)	5,184	5,184	5,184	-	5,184	Total bandwidth = # of copper cales x
Bandwidth of each copper cable (Gb/s)	200	200	200	-	400	Bandwidth of each cable / 2 (unidirectional)
PCB midplane bandwidth (Tb/s)	-	-	-	2,074	-	
Notes	-	-	-	*PCB all to all connection*	-	
# of PCB Midplane (units)	-	-	-	2	-	Total bandwidth = # of PCB Midplane x
Bandwidth of each PCB (Gb/s)	-	-	-	1,036,800	-	Bandwidth of each PCB
CPO/ NPO bandwidth (Tb/s)	-	-	-		1,037	
Notes	-	-	-	-	*L2 scale up among racks*	
# of optical fiber (units)	-	-	-	-	5,184	Total bandwidth = # of copper cales x
Bandwidth of each optical fiber (Gb/s)	-	-	-	-	400	Bandwidth of each cable / 2 (unidirectional)
# of optical engine (units)	-	-	-	-	324	Total bandwidth = # of optical engine x
Data rate of Optical engine (Tb/s)	-	-	-	-	3.2	Bandwidth of each optical engine
Scale out						
Scale out Bandwidth (unidirectional, Tb/s)	**58**	**115**	**115**	**230**	**115**	
Total Switching Capacity (Tb/s)	**346**	**691**	**691**	**1,382**	**691**	**Assuming 3-layer network**
GPU uplink (Tb/s)	58	115	115	230	115	
# of GPU (units)	72	72	72	144	72	GPU uplink = # of GPU per rack x GPU uplink
GPU uplink per chip (Tb/s)	0.8	1.6	1.6	1.6	1.6	speed (800G/ 1.6T/ 3.2T)
# of layer	3	3	3	3	3	
Optical module						
# of optical module (units)	216	432	324	307	153	
Optical module penetration (GSe)	100%	100%	75%	71%	71%	# of optical module = Total switch capacity in
Data rate of optical module (Tb/s)	1.6	1.6	1.6	3.2	3.2	scale-out network x % in optical module /
Attach rate (Optical module ports: GPU)	**3.0**	**6.0**	**4.5**	**2.1**	**2.1**	Data rate of each optical module (1.6T/ 3.2T)
CPO/ NPO						
# of CPO ports (units)	-	-	108	125	63	# of CPO ports = Total switch capacity in
CPO penetration (GSe)	-	-	25%	29%	29%	scale-out network x % in CPO / Data rate of
Data rate of CPO (Tb/s)	-	-	1.6	3.2	3.2	each CPO port (1.6T/ 3.2T)
Attach rate (CPO ports: GPU)	**-**	**-**	**1.5**	**0.9**	**0.9**	
Among which:						
# of optical engine (units)	-	-	108	125	63	# of CPO optical engine = Total switch
Data rate of Optical engine (Tb/s)	-	-	1.6	3.2	3.2	capacity in scale-out network x % in CPO /
Attach rate (Optical engine: GPU)	-	-	**1.5**	**0.9**	**0.9**	Data rate each optical engine (3.2T)
Attach rate summary						
Optical module : GPU - scale out	**3.0**	**6.0**	**4.5**	**2.1**	**2.1**	
Optical engine : GPU - scale up	**-**	**-**	**-**	**-**	**4.5**	
Optical engine : GPU - scale out	**-**	**-**	**1.5**	**0.9**	**0.9**	
Scale out sum	**3.0**	**6.0**	**6.0**	**3.0**	**3.0**	

(1) Shipment period is based on the Nvidia's product roadmap; (2) # of GPU/ NV Switch ASIC/ NIC per rack are based on Nvidia's product roadmap, industry check and our calculation based on the announced specifications; (3) Bandwidth and switching capacity are based on Nvidia's product roadmap.

Source: Company data, Goldman Sachs Global Investment Research

Following the 2026 GTC , where a clear technology roadmap of the next generations of GPU, server rack, and networking solutions are outlined, we present an in-depth analysis of the specification changes for the next two generations of GPU platforms (Vera Rubin and Rubin Ultra). By integrating insights from the company's announcement (link) and our industry checks with the supply chain, we intend to delineate the inter-connection architecture of the forthcoming server racks (Exhibit 5), breakdown the dollar content for each networking component (Exhibit 6), forecast the TAM opportunity for each component (Exhibit 8) and assess the EPS impact for our key coverage names (Exhibit 13). With these, we aim to address the frequently asked investor question about how to evaluate the market size resulting from complex server networking upgrades ahead.

The next generation racks: Networking technology continues to evolve in both scale out (across racks / computing unit) and scale up (within one computing unit). Based on the GTC 2026 announcement (link), we discuss the major four configurations in Vera Rubin and Rubin Ultra platform, to evaluate the TAM opportunities and EPS impact across the supply chain. Separately, we consider the CPO penetration rate in scale-out connections in our analysis (Exhibit 5), which is based on industry checks and our optimistic perspective on CPO adoption. As CPO is a next-generation technology, its pace of adoption will significantly influence the connection TAM opportunity, especially given its dollar content per rack. Detailed specification assumptions are shown in Exhibit 5 and below.

- **Vera Rubin Spec A – NVL72. Scale up** adopts copper cable cartridge, i.e. the Oberon rack. **Scale out** adopts pluggable optical module connections.
- **Vera Rubin Spec B – NVL72 (CPO scale out)**. **Scale up** adopts copper cable cartridge, i.e. the Oberon rack. **Scale out** could use CPO or pluggable optical module, and we assume 25% CPO penetration rate.
- **Rubin Ultra Spec A – NVL144 (CPO scale up). Scale up** adopts PCB midplane for connection, i.e. the Kyber rack. **Scale out** could use CPO or pluggable optical module, and we assume 29% CPO penetration rate.
- **Rubin Ultra Spec B – NVL576 (CPO scale up).** 72 GPU per rack, and eight racks as a full NVL576 (one computing unit). **Scale up** adopts copper cable cartridge for the first layer connection (i.e. Oberon rack design for the connections within the server rack) and CPO for the second layer connection (i.e. the connections between the eight racks). **Scale out** could use CPO or pluggable optical module, and we assume 29% CPO penetration rate.

Based on above, we derive: (1) dollar content per rack across different configurations, (2) value TAM opportunities (dollar content per rack * number of server racks), and (3) implication to supply chain EPS. **Key takeaways:** (1) Rubin Ultra brings dollar content increases across scale up and scale out compared to GB300, (2) Rubin Ultra scale up brings dollar content increases across copper cables, PCB midplane, and CPO switch, (3) pluggable optical modules would continue to increase dollar content increase per rack in scale out compared to GB300 despite our assumption of 25-29% CPO switch penetration rate, (4) CPO appears costly considering 3D packaging, high integration, and the need to upgrade devices to semiconductor processing levels; however, the total cost of ownership (TCO) is attractive especially in high bandwidth requirement (e.g. 6.4T, 12.8T) considering the constraints of pluggable optical module and the power efficiency and energy savings, and (5) On the EPS opportunity, we see most suppliers benefiting from strong EPS contribution from a single configuration that is higher than their 2025 full year EPS, given the AI server racks shipment ramp up and specification upgrades driving the dollar content increase.

Exhibit 6: Dollar content per rack: GB300, Vera Rubin and Rubin Ultra

Volume assumptions are from the spec table (Exhibit 5), ASP assumptions are based on spec table and our industry checks

Dollar content		Vera Rubin Spec A	Vera Rubin Spec B	Rubin Ultra Spec A	Rubin Ultra Spec B
	GB300 NVL72	Vera Rubin NVL 72	Vera Rubin NVL 72 (25% CPO scale out)	Rubin Ultra NVL 144 (29% CPO scale out)	Rubin Ultra NVL 576 (29% CPO scale out)
Shipment period	2H25-2026	2H26-2027	2H26-2027	2H27-2028	2H27-2028
Scale up	Copper cable	Copper cable	Copper cable	PCB Midplane	Copper cable + CPO
Scale out	Optical modules (1.6T)	Optical modules (1.6T)	CPO TOR Switch (1.6T) + Optical module (1.6T)	CPO TOR Switch (3.2T) + Optical module (3.2T)	CPO TOR Switch (3.2T) + Optical module (3.2T)
# of GPU package	72	72	72	144	72
# of NV Switch ASIC	18	36	36	430	430
# of NIC	72	144	144	288	144
Networking costs per rack (US$ k)	**315**	**489**	**504**	**1,113**	**1,169**
Scale-up	140	140	140	381	803
Scale-out	175	349	364	732	366
Scale up dollar content per rack (US$ k)	**140**	**140**	**140**	**381**	**803**
Copper cable - backplane (US$ k)	**93**	**93**	**93**	**-**	**156**
Volume (unit)	5,184	5,184	5,184	-	5,184
ASP (US$)	18	18	18	-	30
Copper cable - flyover in switch tray (US$ k)	**47**	**47**	**47**	**156**	**78**
Volume (unit)	5,184	5,184	5,184	10,368	5,184
ASP (US$)	9	9	9	15	15
PCB midplane (US$ k)	**-**	**-**	**-**	**225**	**-**
Volume (unit)	-	-	-	2	-
ASP (US$)	-	-	-	112,500	-
Optical engine & FAU (CPO/ NPO, US$ k)	**-**	**-**	**-**	**-**	**324**
Volume (unit)	-	-	-	-	324
ASP (US$)	-	-	-	-	1,000
ELS (CPO/ NPO, US$ k)	**-**	**-**	**-**	**-**	**65**
Volume (unit)	-	-	-	-	162
ASP (US$)	-	-	-	-	400
Fiber cable and MPO (CPO/ NPO, US$ k)	**-**	**-**	**-**	**-**	**156**
Volume (unit)	-	-	-	-	5,184
ASP (US$)	-	-	-	-	30
Shufflebox (US$ k)	**-**	**-**	**-**	**-**	**25**
Volume (unit)	-	-	-	-	36
ASP (US$)	-	-	-	-	700
Scale out dollar content per rack (US$ k)	**175**	**349**	**364**	**732**	**366**
Optical module (US$ k)	**173**	**346**	**259**	**491**	**245**
Volume (unit)	216	432	324	307	153
ASP (US$)	800	800	800	1,600	1,600
Optical engine & FAU (CPO/ NPO, US$ k)	**-**	**-**	**86**	**200**	**100**
Volume (unit)	-	-	108	125	63
ASP (US$)	-	-	800	1,600	1,600
ELS (CPO/ NPO, US$ k)	**-**	**-**	**11**	**25**	**13**
Volume (unit)	-	-	27	63	31
ASP (US$)	-	-	400	400	400
Fiber cable and MPO (CPO/ NPO, US$ k)	**2**	**4**	**4**	**6**	**3**
Volume (unit)	108	216	216	216	108
ASP (US$)	18	18	18	30	30
Shufflebox (US$ k)	**-**	**-**	**4**	**10**	**5**
Volume (unit)	-	-	6	14	7
ASP (US$)		700	700	700	700

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 7: CPO switch specification comparison

	Nvidia		Broadcom	
	Quantum-X Photonics	Spectrum-X Photonics	Tomahawk 5 – Bailly	Tomahawk 6 – Davisson
Network	InfiniBand	Ethernet	Ethernet	Ethernet
Switching capacity	115.2Tb/s	409.6 Tb/s	51.2 Tb/s	102.4 Tb/s
# of Switch ASIC	4	4	1	1
Switch ASIC	28.8Tb/s	102.4Tb/s	51.2Tb/s	102.4Tb/s
Ports	144 x 800G	512 x 800G	128 x 400G	64 x 1.6T / 128 x 800G
Speed	200G/lane SerDes	200G/lane SerDes	100G/lane SerDes	200G/lane SerDes
External laser source	18	64	TBA	TBA
Optical engines	72 (1.6T)	128 (3.2T)	8 (6.4T)	16 (6.4T)
Size	4U	5U	4U	TBA

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

Exhibit 8: Scale up / Scale out TAM opportunities

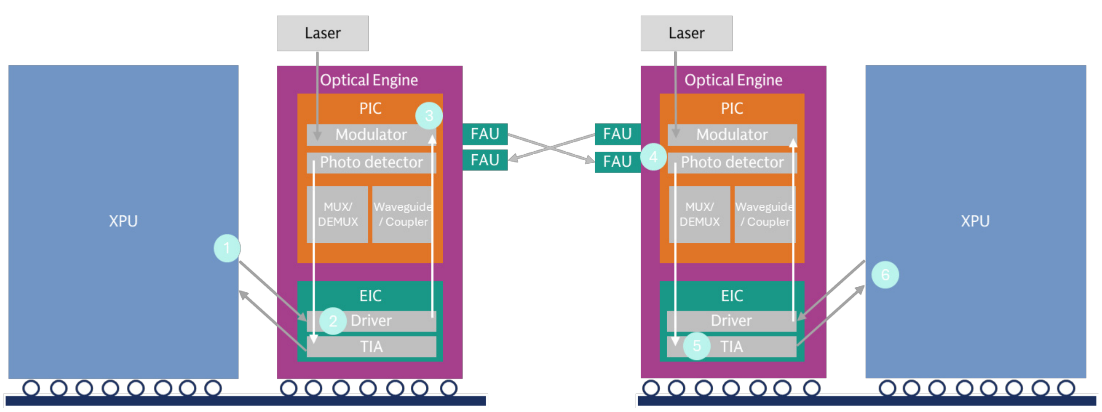
The TAM opportunity is based on the connection content value of each rack (Exhbit 6) multiple by GSe shipment of Vera Rubin / Rubin Ultra racks

Value TAM		Vera Rubin Spec A	Vera Rubin Spec B	Rubin Ultra Spec A	Rubin Ultra Spec B
	GB300 NVL72	Vera Rubin NVL 72	Vera Rubin NVL 72 (25% CPO scale out)	Rubin Ultra NVL 144 (29% CPO scale out)	Rubin Ultra NVL 576 (29% CPO scale out)
Scale up	Copper cable	Copper cable	Copper cable	PCB Midplane	Copper cable + CPO
Scale out	Optical modules (1.6T)	Optical modules (1.6T)	CPO TOR Switch (1.6T) + Optical module (1.6T)	CPO TOR Switch (3.2T) + Optical module (3.2T)	CPO TOR Switch (3.2T) + Optical module (3.2T)
Scle up + Scale out TAM (US$m)	**15,070**	**28,291**	**29,158**	**73,458**	**154,313**
Copper cable - backplane	12,742	25,369	20,375	32,390	52,918
Copper cable - flyover in switch tray	2,234	2,697	7,691	23,494	23,494
PCB Midplane	-	-	624	16,504	1,654
Optical engine & FAU	93	225	225	428	43,196
ELS	-	-	243	643	9,197
Fiber cable and MPO	1	1	1	1	20,530
Shufflebox	1	1	1	1	3,327
Scale up TAM (US$ m)	**6,702**	**8,090**	**8,090**	**25,114**	**105,970**
Copper cable - backplane	4,468	5,393	5,393	-	20,529
Copper cable - flyover in switch tray	2,234	2,697	2,697	10,264	10,264
PCB Midplane	-	-	-	14,850	-
Optical engine & FAU	-	-	-	-	42,768
ELS	-	-	-	-	8,554
Fiber cable and MPO	-	-	-	-	20,529
Shufflebox	-	-	-	-	3,326
Mix %	**100%**	**100%**	**100%**	**100%**	**100%**
Copper cable - backplane	67%	67%	67%	0%	19%
Copper cable - flyover in switch tray	33%	33%	33%	41%	10%
PCB Midplane	0%	0%	0%	59%	0%
Optical engine & FAU	0%	0%	0%	0%	40%
ELS	0%	0%	0%	0%	8%
Fiber cable and MPO	0%	0%	0%	0%	19%
Shufflebox	0%	0%	0%	0%	3%
Scale out TAM (US$ m)	**8,367**	**20,200**	**21,067**	**48,344**	**48,344**
Optical module	8,274	19,976	14,982	32,390	32,390
Optical engine & FAU	-	-	4,994	13,230	13,230
ELS	-	-	624	1,654	1,654
Fiber cable and MPO	93	225	225	428	428
Shufflebox	-	-	243	643	643
Mix %	**100%**	**100%**	**100%**	**100%**	**100%**
Optical module	99%	99%	71%	67%	67%
Optical engine & FAU	0%	0%	24%	27%	27%
ELS	0%	0%	3%	3%	3%
Fiber cable and MPO	1%	1%	1%	1%	1%
Shufflebox	0%	0%	1%	1%	1%
Assumption: GPU Rack forecast (GSe, k units, full lifecycle)					
GB300	48				
Vera Rubin		58	58		
Rubin Ultra				66	132

(1) Spec A come with lower connection value while Spec B come with higher connection value; (2) Read more about GPU rack shipment in our Global Server Model

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 9: How CPO works in data transmission



Source: Company data, Compiled by Goldman Sachs Global Investment Research

Exhibit 10: Our high end estimate imply a CPO TAM totalling US$97bn in 2026-28E

High-end based on GB300, Vera Rubin/Rubin Ultra Spec B; Low-end based on GB300, Vera Rubin/ Rubin Ultra Spec A

Value TAM by year

Value TAM range (high-end, Spec B)	2026E	2027E	2028E
Scale up TAM (US$ m)	**7,228**	**30,697**	**82,837**
Scale out TAM (US$ m)	**10,921**	**27,023**	**39,835**
CPO TAM (US$ m)	**1,024**	**24,840**	**70,881**
Optical engine & FAU	864	16,269	43,858
ELS	108	2,763	7,961
Fiber cable and MPO	10	4,734	15,965
Shufflebox	42	1,074	3,096
Value TAM range (low-end, Spec A)	**2026E**	**2027E**	**2028E**
Scale up TAM (US$ m)	**7,228**	**12,321**	**20,358**
Scale out TAM (US$ m)	**10,771**	**26,408**	**39,733**
CPO TAM (US$ m)	**-**	**3,557**	**12,093**
Optical engine & FAU	-	3,007	10,223
ELS	-	376	1,278
Fiber cable and MPO	-	28	96
Shufflebox	-	146	497

(1) CPO TAM refers to CPO components applied in both scale up and scale out connections; (2) By year estimate is based on the Server rack allocation among years and the full lifecycle TAM in Exhibit 7; (3) High end is based on Spec B and Low end on Spec A of each model

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 11: Our high end estimate imply a demand for 110k scale out CPO switch in 2028E

High-end based on GB300, Vera Rubin/Rubin Ultra Spec B; Low-end based on GB300, Vera Rubin/ Rubin Ultra Spec A

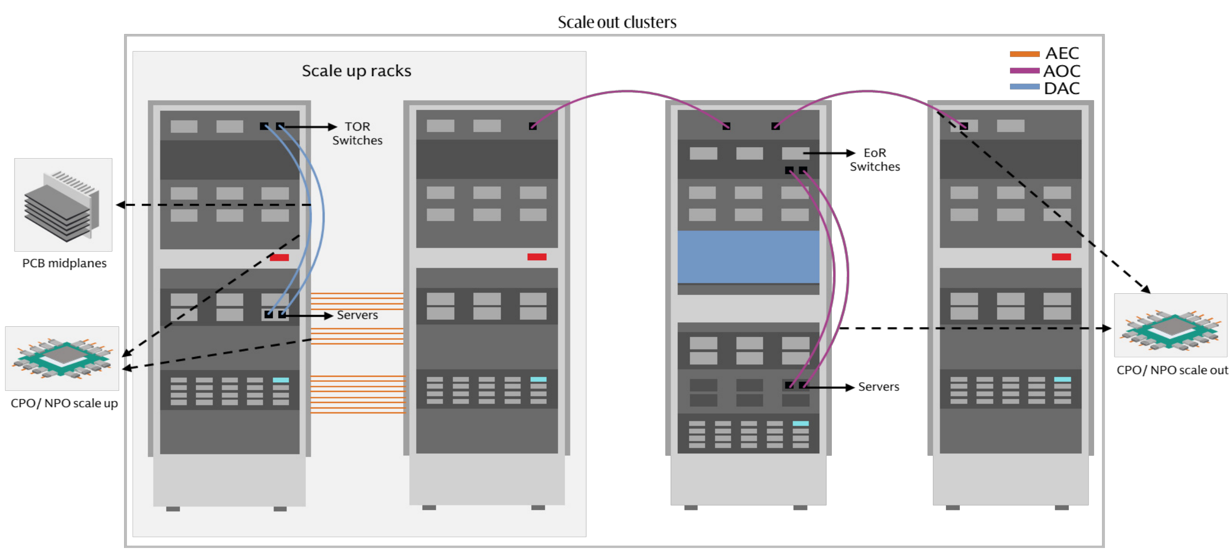
Volume TAM by year

Volume TAM range (high-end, Spec B)	2026E	2027E	2028E
CPO TAM (k units)			
Optical engine & FAU	1,080	16,027	40,172
ELS	270	6,907	19,902
Fiber cable and MPO	540	158,674	532,330
Shufflebox	60	1,535	4,423
Key data			
Nvidia AI rack shipment (k units)	*50*	*77*	*121*
Scale out CPO penetration	*5%*	*25%*	*29%*
Scale out CPO switch (k units)*	*15*	*88*	*110*
Volume TAM range (low-end, Spec A)	**2026E**	**2027E**	**2028E**
CPO TAM (k units)			
Optical engine & FAU	-	1,879	6,389
ELS	-	940	3,195
Fiber cable and MPO	-	940	3,195
Shufflebox	-	209	710
Key data			
Nvidia AI rack shipment (k units)	*50*	*77*	*121*
Scale out CPO penetration	*0%*	*11%*	*27%*
Scale out CPO switch (k units)*	*-*	*26*	*89*

(1) CPO TAM refers to CPO components applied in both scale up and scale out connections; (2) assume 72 optical engines per scale out switch (*); (3) By year estimate is based on the Server rack allocation among years and the full lifecycle TAM in Exhibit 7; (4) High end is based on Spec B and Low end on Spec A of each model

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 12: Connections in data center: Scale-up vs. Scale out



TOR Switch: Top of rack switch; EoR Switch: End of row switch

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

Exhibit 13: Earning implications to key suppliers

Earnings impact based on the Value TAM (Exhibit 8) x market share assumption (GSe) x margin assumption (GSe) for each supplier

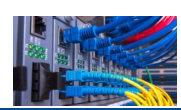
Earning implications				Vera Rubin Spec A	Vera Rubin Spec B	Rubin Ultra Spec A	Rubin Ultra Spec B	
Model		*2025 Actual*	GB300 NVL72	Vera Rubin NVL 72	Vera Rubin NVL 72 (25% CPO scale out)	Rubin Ultra NVL 144 (29% CPO scale out)	Rubin Ultra NVL 576 (29% CPO scale out)	Products
Shipment period			2H25-2026	2H26-2027	2H26-2027	2H27-2028	2H27-2028	
Key assumptions			**Key assumptions**					
Scale up			100% copper cables	100% copper cables	100% copper cables	PCB miplane	L1 copper cables; L2 CPO	Key assumptions are based on the spec table (Exhibit 5) OM refers to optical module
Scale out			100% pluggable OM (1.6T)	100% pluggable OM (1.6T)	75% pluggable OM (1.6T); 25% CPO	71% pluggable OM (3.2T); 29% CPO	71% pluggable OM (3.2T); 29% CPO	
EPS implications (LCY)		*2025 Diluted EPS*	**EPS opportunities (LCY)**					
Optical module/ Optical engine								
Innolight	300308.SZ	*9.8*	6.0	14.6	11.4	24.8	28.6	Optical engine, Optical module
Eoptolink	300502.SZ	*9.5*	4.2	10.0	8.0	17.5	21.6	Optical engine, Optical module
TFC Optical	300394.SZ	*2.7*	2.7	3.9	3.3	6.0	12.4	FAU, Optical module
Sumitomo	5802.T	*345.9*	-	-	29.6	69.2	311.0	FAU, Optical engine
Mitsubishi	6503.T	*162.9*	-	-	8.8	23.3	98.6	Optical engine
Furukawa	5801.T	*747.3*	-	-	103.0	245.5	1,092.1	FAU, Optical engine
Fujikura	5803.T	*582.4*	-	-	18.8	24.9	153.6	FAU
CW laser/ EML								
Landmark	3081.TWO	*4.6*	2.3	6.1	7.1	14.4	73.4	CW laser
VPEC	2455.TW	*3.0*	0.6	1.7	1.9	3.9	20.1	EPI wafer
Sumitomo	5802.T	*345.9*	8.6	21.0	22.5	49.6	142.4	CW laser/EML
Mitsubishi	6503.T	*162.9*	4.1	9.7	8.3	21.3	43.9	CW laser/EML
Furukawa	5801.T	*747.3*	1.2	7.0	20.3	41.3	210.6	CW laser/EML
PCB								
Victory Giant	300476.SZ	*5.0*	-	-	-	13.3	-	PCB Midplane
WUS	002463.SZ	*2.0*	-	-	-	2.4	-	PCB Midplane
Unimicron	3037.TW	*4.3*				0.9		PCB Midplane
CCL								
EMC	2383.TW	*40.8*	-	-	-	100.7	-	CCL for PCB Midplane
Shengyi	600183.SS	*1.3*	-	-	-	0.3	-	CCL for PCB Midplane
Net income implications (US$ m)		*2025 Net income*	**Net income opportunities (US$ m)**					
Optical module/ Optical engine								
Innolight	300308.SZ	*1,510*	947	2,286	1,785	3,894	4,497	Optical engine, Optical module
Eoptolink	300502.SZ	*1,326*	577	1,394	1,111	2,435	3,004	Optical engine, Optical module
TFC Optical	300394.SZ	*290*	291	421	357	651	1,348	FAU, Optical module
Sumitomo	5802.T	*1,740*	-	-	149	348	1,565	FAU, Optical engine
Mitsubishi	6503.T	*2,142*	-	-	116	306	1,297	Optical engine
Furukawa	5801.T	*340*	-	-	47	112	497	FAU, Optical engine
Fujikura	5803.T	*1,037*	-	-	33	44	273	FAU
CW laser								
Landmark	3081.TWO	*14*	7	19	22	44	225	CW laser
VPEC	2455.TW	*18*	4	10	12	24	123	EPI wafer
Sumitomo	5802.T	*1,740*	43	105	113	250	717	CW laser/EML
Mitsubishi	6503.T	*2,142*	53	128	109	279	577	CW laser/EML
Furukawa	5801.T	*340*	1	3	9	19	96	CW laser/EML
PCB								
Victory Giant	300476.SZ	*603*	-	-	-	1,622	-	PCB Midplane
WUS	002463.SZ	*535*	-	-	-	647	-	PCB Midplane
Unimicron	3037.TW	*222*	-	-	-	45	-	PCB Midplane
CCL								
EMC	2383.TW	*488*	-	-	-	1,188	-	CCL for PCB Midplane
Shengyi	600183.SS	*449*	-	-	-	114	-	CCL for PCB Midplane

(1) We estimate the potential EPS/ Net income contributed from a certain server model. (2) We assume all the lasers for CPO are CW lasers. (3) OM refers to optical module; (4) Eoptolink and Shengyi's 2025 financials are GSe as results are not announced.

Source: Company data, Goldman Sachs Global Investment Research

(6) Choice of connection: PCB vs. Copper vs. Optics

Exhibit 14: Copper vs. Optics vs. PCB



	PCB	Copper	Optics
Typical distance	<0.5m	5-10m	>50m
Speed	up to 224G	448G	1.6T/ 3.2T
Power consumption	Lowest	Low	Higher, needed electro-optical conversion
Signal integrity	The most challenge (Dielectric Loss, Conductor loss, Skin effect)	Challenge (Conductor loss, Skin effect)	Stable (Dispersion)
EMI	Sensitive	Medium	Immune
Cost	Lowest at scale, but costs will increase drastically if migrate to higher speed/ frequency	Lower than Optics	Higher, needed transceivers

Source: Company data

Copper cables and PCBs are commonly used materials for short-distance connections. PCBs handle the short connections within servers, while copper cables connect inside or between servers. Both offer lower cost and power consumption in short distances; however, signal quality degrades rapidly over longer distances or higher speeds, leading to **optical fiber connections** to stand out for long distance or high speed interconnections. AI data centers are being designed for faster bandwidth, larger scale, easier deployment and lower costs. There are many different options for AI data center connections (as we list in Exhibit 15), and connection technologies change over time. **Major trends recently include** (1) copper cables evolving from DAC to ACC to AEC, toward longer distance connection, (2) PCBs evolving from intra-tray use to intra-rack connections, and (3) optics evolving from scale out to scale up, with AOC and CPO switches, covering shorter distance connection.

Exhibit 15: From PCB to Fiber: different types of connections for different distances

Category	PCB		Copper			Optics		
Connection materials	PCB traces	PCB midplane	DAC (Direct Attach Copper)	ACC (Active Copper Cable)	AEC (Active Electrical Cable)	AOC (Active Optical Cable)	Transceiver + Fiber (DR)	Transceiver + Fiber (FR)
Distance	<1m	<1m	0.5-3m	7-15m	5-30m	30-100m	30-500m	500m-2km
Cost	Lowest	Higher	Lowest	Low	Medium	Higher	Higher	Higher
Medium	PCB	PCB	Twinax Copper	Twinax Copper + Redriver	Twinax Copper + Retimer	Multimode Fiber with integrated transceivers (VCSEL)	Singlemode Fiber + discrete DR transceivers	Singlemode Fiber + discrete FR transceivers
Typical application	Same tray: GPU to GPU	Intra-rack: GPU to GPU	Intra-rack: GPU to GPU, GPU to ToR	Intra-/ Inter-rack: GPU to GPU, GPU to ToR	Intra-/ Inter-rack: GPU to GPU, GPU to ToR	Inter-rack: GPU to ToR	Intra-builidng: ToR to Spine, Leaf to Spine	Inter-building: Spine to super spine
Scale up or Scale out	Scale up	Scale up	Scale up	Scale up (Inter-rack)	Scale up (Inter-rack)	Scale up (Inter-rack), Scale out	Scale out	Scale out

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

Scale up configurations: (1) From short to longer distances: In general, PCB traces are for connections within a server tray, DAC copper cables for connections within a server rack (e.g. GB200's copper cartridge) and AEC copper cables for connections among server racks (e.g. AmazonTrn2-Ultra64). AEC cables come with retimers that drives the connection distance to reach 5-30m (vs. <3m of DACs). **(2) PCB midplane:** Server trays and switch trays could be connected directly to a PCB midplane, which is likely to feature M9 CCL materials and 78 or more layers. The initial costs could be higher, though the midplane could be easier to assemble and more competitive in costs-to-performance ratio for higher speed requirements (e.g. Rubin Ultra NVL144). **(3) Optics** show strength in longer interconnections and larger bandwidth, which Google uses in part of its scale-up 3D torus. To meet the larger bandwidth demands and shorten connection distances, Optics connections are expanding from pluggable optical modules to onboard optics (NPO), and co-packaged optics (CPO), which could be seen in scale up configurations (e.g. Rubin Ultra NVL576 level 2 scale up). **Scale out configurations:** in general, optics are for AI cluster scale out given the requirement on high speed and larger interconnection size.

Exhibit 16: Connection solutions of mainstream AI servers

Model		Year	Scale-up	Scale-out
Nvidia	GB200	2024	Copper	Optical (400G, 800G)
	GB300	2025	Copper	Optical (800G, 1.6T)
	VR200 (1.6T)	2026	Copper	Optical (800G, 1.6T)
	Rubin Ultra	2027	Copper, PCB, Optical	Optical (1.6T, 3.2T)
Google	V6	2024	Copper, Optical (800G)	Optical (800G)
	V7	2025	Copper, Optical (1.6T)	Optical (1.6T)
	V8e	2026	Copper, Optical	Optical
	V8p	2026	Copper, Optical	Optical
Amazon	Trainium 2	2025	Copper	Copper, Optical (400G)
	Trainium 3 (Teton 3 PDS/ MAX)	2026	Copper	Copper, Optical
	Trainium 4	2027	Copper	Copper, Optical
Meta	MITA-T V1 (Minerva)	2026	Copper	Optical (800G)
Huawei	Cloud Matrix 384	2025	Copper, Optical	Optical

400G/ 800G/ 1.6T/ 3.2T refers to the fastest data rate in the network, while there can be lower speed ports in the network

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

(7) Optics: speed upgrade continues

Exhibit 17: Roadmap of data center connection speed

Timeline	2024 Q1	2024 Q2	2024 Q3	2024 Q4	2025 Q1	2025 Q2	2025 Q3	2025 Q4	2026 Q1	2026 Q2	2026 Q3	2026 Q4	2027 Q1	2027 Q2	2027 Q3	2027 Q4	2028 Q1	2028 Q2	2028 Q3	2028 Q4
400G	20%	22%	25%	30%	27%	16%	15%	9%	5%	5%	8%	6%	4%	4%	3%	1%	1%	1%	2%	1%
800G		1%	3%	4%	4%	17%	24%	41%	20%	21%	29%	26%	19%	23%	36%	27%	20%	18%	30%	23%
1.6T						2%	6%	11%	12%	12%	19%	28%	27%	26%	24%	27%	23%	25%	35%	26%
3.2T														6%	10%	16%	15%	16%	15%	11%
6.4T																				

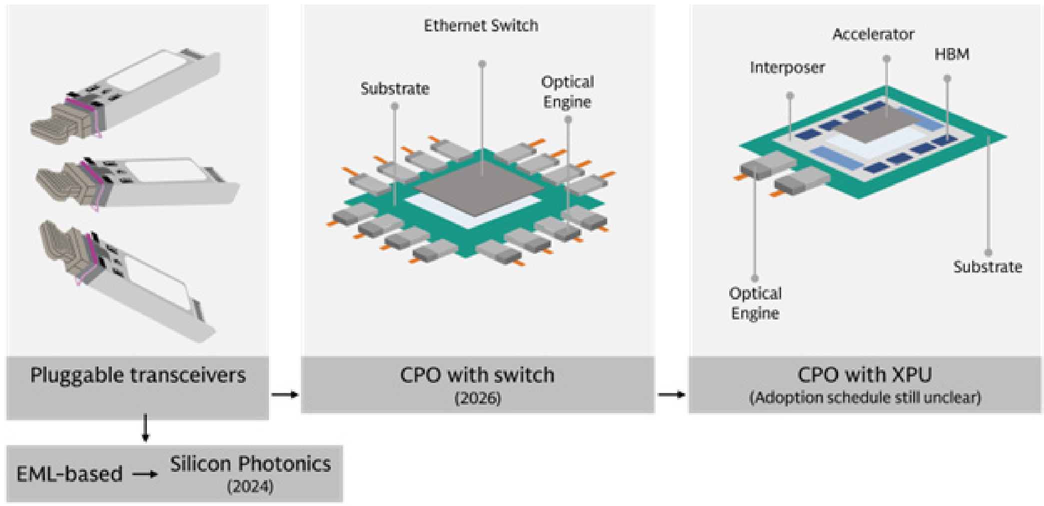
Verification and test | Small sample | Mass volume | Mainstream | Declining

Penetration rates do not sum up to 100%, as there are modules below 400G; Data from our Global Optical Module TAM.

Source: Company data, Goldman Sachs Global Investment Research

We expect the speed migration to continue through 2028E, from 800G to 1.6T in 2026, and toward 3.2T and above in the following years, and followed by China Cloud speed migration to lengthen the migration cycle. To meet the increasing demand on bandwidth, power consumption, and miniaturization, the form of optical connection is evolving (Exhibit 18): (1) pluggable optical module are shifting towards silicon photonics from EML, which come with higher integration, lower cost and reduced reliance on laser supply, (2) expanding from pluggable optical module to onboard optics (NPO) and co-packaged optics (CPO), covering short distance connection with high bandwidth and better power efficiency. CPO will initially be integrated with switch ASIC, followed by XPUs (GPU, CPU, ASICs, etc.).

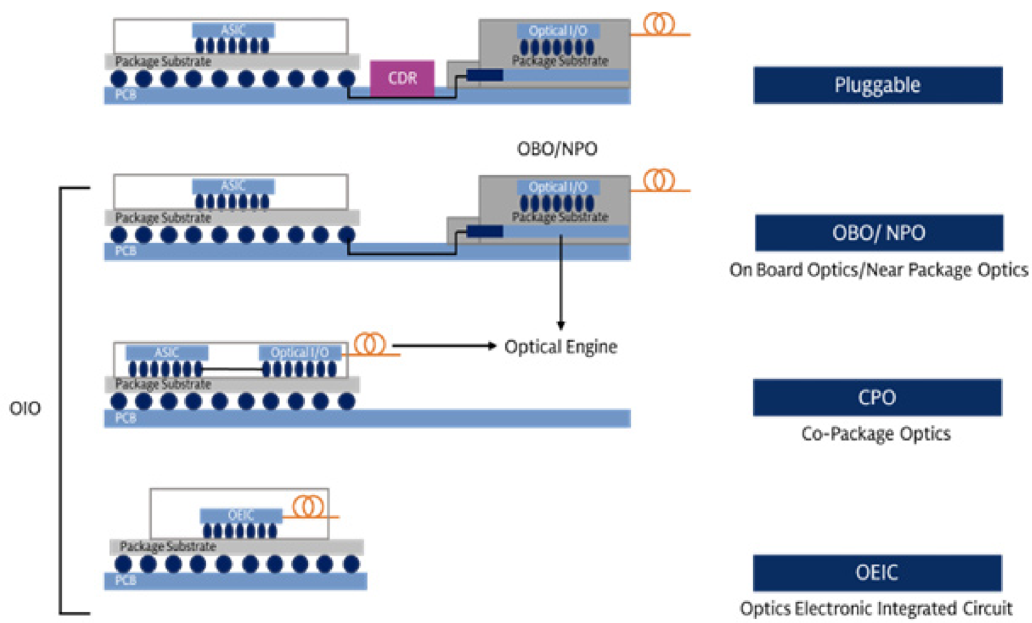
Exhibit 18: Optics technology migrations



Source: Company data, Data compiled by Goldman Sachs Global Investment Research

(8) CPO with Switch kick off in 2026

Exhibit 19: CPO Technology migrations



Source: Company data, Data compiled by Goldman Sachs Global Investment Research

CPO expands optics to cover short distance connection and higher bandwidth. It places optical engines as close as possible to the chips, shortening the electrical paths from several centermeters to millimeter level and lower power consumption. The shorter transmission path could also reduce latency and save DSPs and retimers, along with the power consumption by these devices. The higher integration also brings smaller size. On other hand, CPO requires supply chain technology migration rather than single devices upgrade, which could take time to develop; in addition, the co-packaging leads to higher maintenance costs: in a pluggable optical module, if the optical engine fails, one replaces the optical module, and the switch system remains intact, while in (1) onboard optics / NPO, it would need to replace the switch PCB, (2) CPO with the switch, failure would affect the switch ASIC, and (3) CPO with XPU, failure would affect the XPU (e.g. GPU, CPU, NPU, etc.). The lifecycle of PIC and EIC are different, with PIC are more delicate, leading to the design of pluggable optical module. As a result, we expect (1) pluggable optical module would co-exist with NPO / CPO, and on continuous speed migration toward 3.2T, (2) CPO would be more attractive to clients in short distance and higher bandwidth that pluggable optical module could not achieve, and (3) pluggable optical module suppliers would also enjoy new optics devices opportunities in NPO / CPO, such as optical engine, FAU, ELS module, etc.

Exhibit 20: CPO: key development of major players

Key players	Progress	Progress details	Highlights
Nvidia	- CPO Switch commercially avaiable in 2026 (Scale out)	**Mar-2025:** Announced CPO switch (Quantum-X InfiniBand, Spectrum-X Ethernet) **Early 2026:** Commercial availability of CPO switch	Adopt **MRM (Micro Ring Modulator)** technology, achieving higher density and efficiency
Broadcom	- Davisson (102.4T) CPO switch sampling in Oct 2025 (Scale-out and scale-up)	**Mar-2022**: world's first 25.6T CPO Demo **June-2023:** 51.2T CPO sampling **Mar-2024:** Bailly (51.2T) CPO switch deliverd to customers **Oct-2025:** Davisson (102.4T) CPO switch delivered to customers	Adopt **MZM** (Mach-Zehnder Modulator), which is more matured, while also developing MRM
Marvell	- CPO ethernet swith sampling in 2027 (Scale-out) - Developing CPO for XPUs (Scale-up)	**Feb-2026:** Acquired Celestial AI, a startup focusing on CPO for XPUs **2027:** CPO (204T) Ethernet switch sampling	CPO solution to combine with custom XPUs for CSPs
Ranovus x Mediatek	Announced co-developed CPO for ASIC in 2024	**Mar-2024:** Announced Odin CPO solutions (6.4T) collaborating with Mediatek's ASIC platform	Targeting CPO technology on XPU

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

Exhibit 21: CPO development: Nvidia and Broadcom taking the lead
Nvidia and Broadcom's ecosystem

Ecosystem	Nvidia	Broadcom
Time line	**Mar-2025:** Announced CPO switch (Quantum-X InfiniBand, Spectrum-X Ethernet) **Early 2026:** Commercial availability of CPO switch	**Oct-2025:** Davisson (102.4T) CPO switch delivered to customers **2026:** Davisson to start production
Compute		
GPU	Nvidia (Blackwell, Rubin etc)	Open (Nvidia, AMD, Intel etc)
Network		
Switch ASIC	Nvidia	Broadcom (Tomahawk 5/ Tomahawk 6)
Switch system	Nvidia (Spectrum-X, Quantum-X)	Open ecosystem (Delta Electronics, Micas Networks)
Optics		
CPO chip		
CPO platform name	N.A.	Bailly/ Davission
CPO chip fabrication	TSMC (2330.TW)	TSMC (2330.TW)
CPO chip test	SPIL (3711.TW)	TBA
Other componets		
Optical engine	TFC Optical (300394.SZ), Browave (3163.TWO), TSMC (2330.TW), Innolight (300308.SZ), Eoptolink (300502.SZ), PCL Tech (4977.TW)	
FAU	FOCI (3363.TWO), TFC Optical (300394.SZ), Innolight (300308.SZ), Advanced Fiber Resources (300620.SZ)	
CPO connector	Nextronics (8417.TWO)	COXOC (6205.TW)
Optical connectors	Senko (Private)	TBA
Shuffle Box	Browave (3163.TWO)	
Laser Sources/ CW Laser	Sumitomo (8053.T), Furukawa (5801.T)/ VPEC (2455.TW), Landmark (3081.TWO), YJ Semitech (688498.SS), Lumentum (LITE), Coherent	
ELS module	Senko (Private), Sumitomo (8053.T), Innolight (300308.SZ), PCL Tech (4977.TW)	
Fiber	Corning (GLW)	
Cage thermal module	Nextronics (8417.TWO)	COXOC (6205.TW)
System-level assembly	Hon Hai (2317.TW), Fabrinet (FN)	TBA
Equipment		
CPO coupling	Robotechnik (300757.SZ), ASMPT (0522.HK), All Ring (6187.TWO)	
CPO test	Robotechnik (300757.SZ), All Ring (6187.TWO)	

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

Exhibit 22: CPO Switch BoM breakdown, by value (GSe)

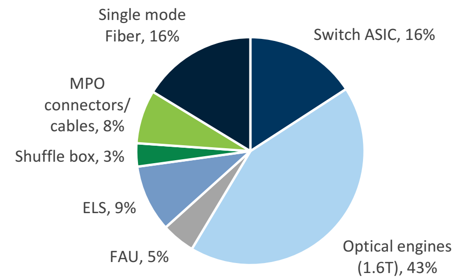
CPO switch BoM (Quantum-X Photonics)

US$	#	ASP	Value
Switch ASIC	4	3,000	12,000
Optical engines (1.6T)	72	450	32,400
FAU	72	50	3,600
ELS	18	400	7,200
Among which: CW laser (300mw)	144	30	4,320
Shuffle box	1	2,500	2,500
MPO connectors/ cables	144	40.0	5,760
Single mode Fiber	1,152	11	12,343
BoM			**75,803**
Markup			62,220
Selling price			**130,000**

ASP estimates are based on industry checks

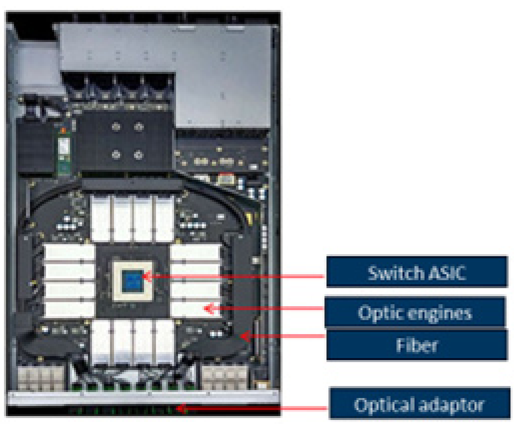
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 23: CPO Switch BoM breakdown, by % (GSe)



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 24: NPO Switch by Ruijie



Picture from Ruijie

Source: Company data

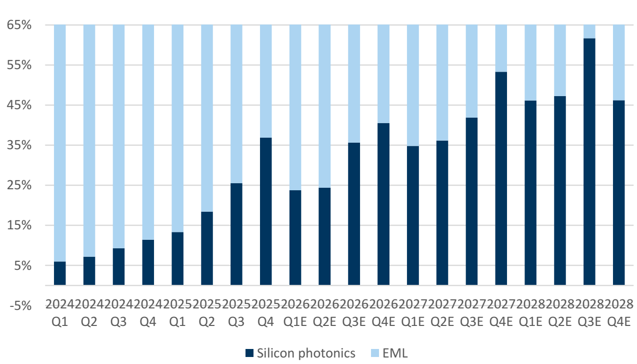
Exhibit 25: NPO Switch by Ruijie

Picture from Ruijie

Source: Company data

(9) Pluggable optical modules: SiPh-based in expansion

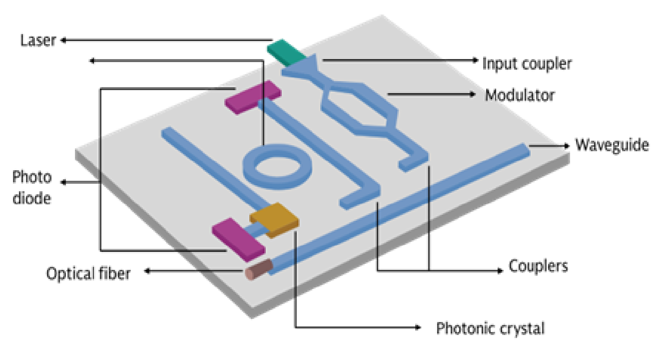
Exhibit 26: We expect SiPh's penetration in datacom market to increase from 6% in 1Q24 to 46% in 4Q28E



Global Optical Module TAM.

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 27: Inside a Silicon photonics chip



Source: Company data

We expect the adoption of silicon photonics in optical transceiver modules to grow from 6% in 1Q24 to 45% in 4Q28 (Exhibit 26). Silicon Photonics provides advantage over traditional discrete optical transceivers due to (1) a higher level of integration and smaller size, (2) lower power consumption, and (3) lower costs. These advantages will become more prevalent when the industry migrates to faster speeds. Nevertheless, the EML would also co-exist in AI data center, especially for long distance transmission given CW lasers require high power to deliver similar performance to EML in long distances. In short distance, some clients would still choose EML considering it is a long-established technology with a longer track record, and the reliability of the network is critical for AI computing, and GPU remains the major cost contributor, making the cost reduction from the light source less significant. The price of like for like products declines as scale ramps up, similar to many other technology components; nevertheless, the speed migration toward 800G / 1.6T / 3.2T would continue to drive the blended ASP expansion. Gross margin of optical module suppliers will ramp to 48%-55%, driven by product mix migration, as higher speed products would shift towards SiPh-based optical modules, benefiting from lower laser costs.

Exhibit 28: 800G: SiPh has 26% BoM advantage and 15% price advantage
800G Optical module BoM

800G BoM (US$)	EML		Silicon Photonics		Diff
Components	#	Value	#	Value	Value
TOSA (excl. laser, driver)	1	15	-	-	(15)
Laser	8 x 100G EML	96	4 x 70mw	16	(80)
Driver	2	20	2	20	-
ROSA (excl. TIA)	1	20	-	-	(20)
TIA	2	20	2	20	-
Silicon Photonics chip	-	-	2	40	40
DSP	1	80	1	80	-
PCBA	1	30	1	25	(5)
Others		29		29	-
Total BoM		310		230	-80
Cost advantage of SiPh					-26%
ASP		430		365	-65
GM		28%		37%	-23%
Price advantage of SiPh					-15%

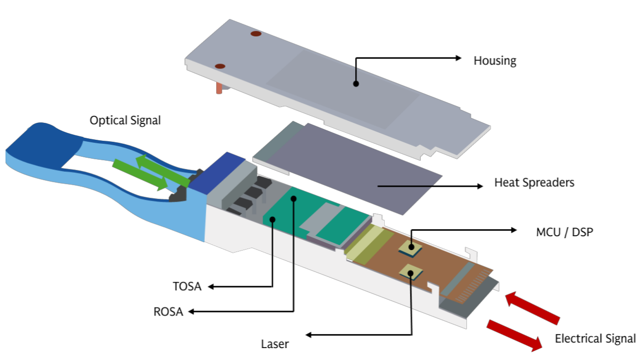
Source: Company data, Data compiled by Goldman Sachs Global Investment Research

Exhibit 29: 1.6T: SiPh has 32% BoM advantage and 20% price advantage for 1.6T applications
1.6T Optical module BoM

1.6T BoM (US$)	EML		Silicon Photonics		Diff
Components	#	Value	#	Value	Value
TOSA (excl. laser, driver)	1	15	-	-	(15)
Laser	8 x 200G EML	160	4 x 70mw	16	(144)
Driver	2	30	2	30	-
ROSA (excl. TIA)	1	60	-	-	(60)
TIA	2	30	2	30	-
Silicon Photonics chip	-	-	2	70	70
DSP	1	130	1	130	-
PCBA	1	35	1	25	(10)
Others		40		40	-
Total BoM		500		341	-159
Cost advantage of SiPh					-32%
ASP		1,000		800	-200
GM		50%		57%	21%
Price advantage of SiPh					-20%

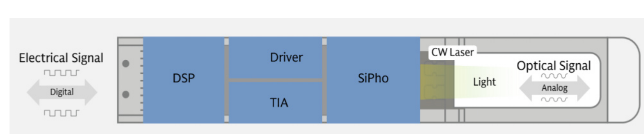
Source: Company data, Data compiled by Goldman Sachs Global Investment Research

Exhibit 30: EML-based optical transceivers: more discrete devices inside



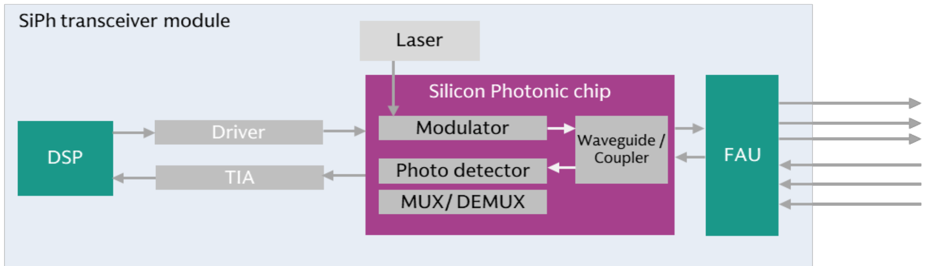
Source: Company data

Exhibit 31: Silicon photonic optical transceivers: higher integration with simplified structure



Source: Company data

Exhibit 32: Silicon photonic optical transceivers: how data transmission works



Source: Company data, Compiled by Goldman Sachs Global Investment Research

(10) Light sourcing: Supply chain and Shortage

Exhibit 33: Optical chip supply chain

		Substrates		
Substrate	**InP substrate**	JX Advanced Metals, Freiberger, Sumitomo Electric, AXT, Yunnan Germanium	**GaAs substrate**	Sumitomo Electric, AXT, Yunnan Germanium

		EML-based		SiPh-based
Photonics Chips	**EML transmitters**	IDM: **Lumentum, Coherent, Broadcom, Sumitomo, Mitsubishi**, YJ Semi, Source Photonics, Everbright Photonics, Shijia Photons, Accelink	**CW Lasers**	IDM: **Sumitomo**, Broadcom, Lumentum, Mitsubishi, Coherent, YJ Semi, Shijia Photons, Everbright Photonics, Accelink EPI wafer + laser chip: **Landmark, Landmark + LuxNet/ TrueLight, VPEC + Furukawa**
	Photodiode	IDM: **Broadcom** EPI wafer + PD chip: **IET / VPEC + Lumentum/ Coherent/ Mitsubishi/** Hamamatsu/ Accelink/ GCS	**SiPh Photonic IC (PIC)**	Design and Packaging: **Lumentum, Coherent, Broadcom, Innolight, Eoptolink, Accelink, Mellanox + TFC Optical, CISCO** Foundry: Towerjazz, GlobalFoundries, TSMC

		EML-based / SiPh- based
Modules	**Optical modules**	Innolight, Coherent (Finisar), Broadcom, Lumentum, Eoptolink, Accelink, Fabrinet, Huawei, Halma Plc

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

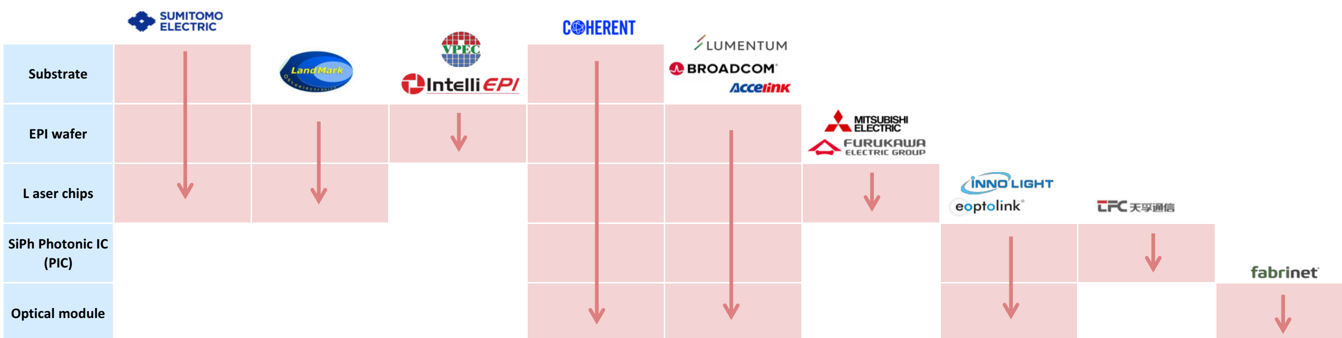
Supply tightness remains in 2026, across both EML and CW lasers, due to (1) strong demand driven by AI servers ramp up, speed migration, and optical connections expansion, (2) InP substrate supply constraints, which are used in both EML and CW lasers, and across PD (receivers) and LD (transmitters), and under geopolitical tension / export controls by the China government, and (3) it takes time for capacity expansion and ramp up across the supply chain. Nevertheless, we see continuous capacity expansion plans from the supply chain, such as: VPEC plans to expands InP MOCVD from 60 units to 64 units in 2H26, both Landmark and YJ Semi commits on significant capacity expansion in 2026, Lumentum plans to expand capacity by 40% from CY3Q25 to CY2Q26, and likely to bring more capacities online in 2026 (Read more in FY2Q26 earnings call), and Coherent has also committed to doubling the capacity (Read more in FY2Q26 earnings call). Overall, we expect light source supply to remain tight through 2027, and could turn more balanced in 2H28 post supply chain capacity expansion, or a slowdown in AI servers specification upgrades as the industry shifts to inferencing from training, or ease of geopolitical tension / export controls by the China government.

Exhibit 34: Light source supply

2025 Q1	2025 Q2	2025 Q3	2025 Q4	2026 Q1E	2026 Q2E	2026 Q3E	2026 Q4E	2027 Q1E	2027 Q2E	2027 Q3E	2027 Q4E	2028 Q1E	2028 Q2E	2028 Q3E	2028 Q4E
Very tight										Tight				Balance	

Source: Goldman Sachs Global Investment Research

Exhibit 35: Different level of vertical intergration of optical chip suppliers



As of Apr 2026

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

VCSEL: Vertical-Cavity Surface-Emitting Laser

Light sourcing in CPO could also vary: CW lasers stand out as the most widely adopted light source in optical modules, and could serve longer-distance connection, fulfilling both scale out and scale up. **VCSEL** also benefits from technology readiness and has higher energy efficiency (lower power consumption) than CW laser solutions. Although its effective reach is shorter than that of CW laser, the distance is sufficient for scale up. **MicroLED** is another potential choice in scale up, with high energy efficiency, and low latency, while the technology readiness is lower compared to CW lasers and VSCEL.

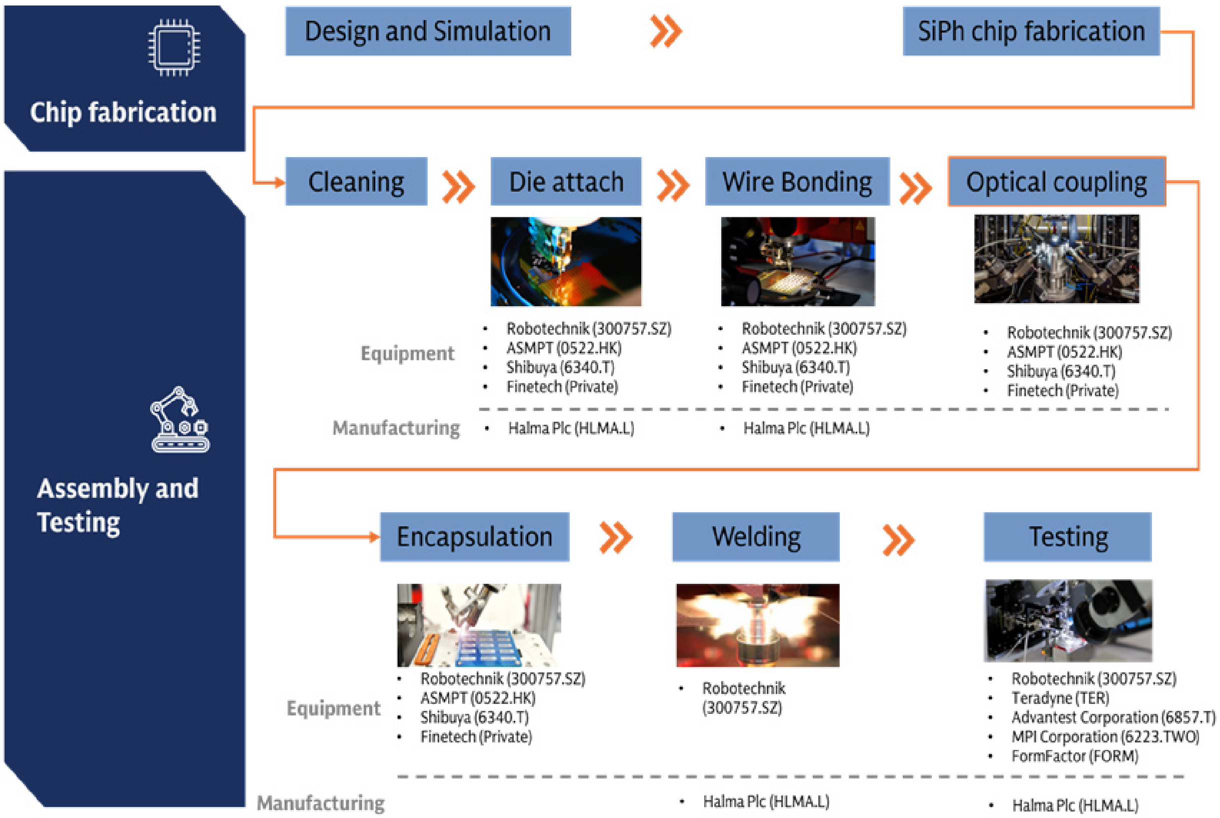
Exhibit 36: Different choices of laser for CPO

	SiPh + CW Laser	VCSEL	MicroLED
Energy efficiency	Lower	High	High
Effective reach (meter)	>1km	<100m	<20m
Latency	Low to Medium	Low to Medium	Low
Cost per bit	Medium	Low	Low
Technology readiness	High	High	Low

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

(11) Manufacturing: how to make SiPh optical modules and engines in CPO

Exhibit 37: Optical module assembly and test process and key equipment suppliers



Optical coupling: Highly impacts production yields
- Sub-micron alignment precision is required
- Compounded Failure: In a co-packaged environment, the failure of a single coupling channel can lead to the rejection of the entire module
- Irreversibility: Once the fiber is glued or laser-welded to the PIC, it is nearly impossible to rework

Testing and inspection: Highly impacts production yields
- The complicated combination of multiple components, including PIC, EIC, lasers and FAU means that the yield rate of each step is vital
- "Testing Shift Left", the final product is integrated with expansive GPUs, and therefore it's vital to test and discover bad dies as early as possible
- Optical alignment need to be ±0.1µm, positing high requirement on coupling test & inspection

Source: Company data, Compiled by Goldman Sachs Global Investment Research

(12) Attach rate: Pluggable optical modules to GPU / ASIC in scale out

Exhibit 38: Optical transceiver attach rate

Model		Year	Attach rate (GSe)	Data rate
Nvidia	GB200	2024	**1: 2~3**	800G
	GB300	2025	**1: 2~3**	1.6T
	VR200	2026	**1: 4~6**	1.6T
	Rubin Ultra	2027	**TBA**	3.2T (GSe)
Google	V6	2024	**1:4**	800G
	V7	2025	**1:4**	1.6T
Amazon	Trainium 2	2025	**1:4**	400G
	Trainium 3 (Teton 3 PDS/ MAX)	2026	**1:4**	TBA
Meta	MITA-T V1 (Minerva)	2026	**1:8~12**	800G (GSe)
Huawei	Cloud Matrix 384	2025	**1:18**	400G
Biren	BR20x	2026	**TBA**	400G/800G

400G/ 800G/ 1.6T/ 3.2T refers to the fastest data rate in the network, while there can be lower speed ports in the network

Source: Company data, Compiled by Goldman Sachs Global Investment Research

The Chip-to-optical module attach ratio depends on **(1) network structure**: a large cluster with 10 thousand GPUs requires three layers of network, while smaller clusters can be supported by two layers. **(2) the adoption % of optics** in connections. Nvidia's upcoming VR200 racks will come with an attach ratio of 1: 4~6 (1.6T), doubling comparing to GB300's 1: 2~3 (1.6T). The increase of optical module usage is driven by the increase in port rate on the server side (i.e. VR200's compute tray support 1.6T per GPU, while GB300's compute tray is at 800G per GPU), while the data rate at the networking side remains the same at 1.6T. The Optical module attach rate of Google and Amazon ASIC are at similar level of 1:4, as they adopt copper cables and OCS switch in scale-up/ scale-out networking. Meta's ASIC can come with a higher attach ratio of 1:8~ 1:12 (800G), per our industry check, given their complicated DSF (Disaggregated Scheduled Fabric) network design. Similarly, Huawei's Cloud Matrix 384 comes with attach ratio of 1:18 as it adopts all optics connection. Other Chinese GPU/ ASIC other than Huawei usually use a standardized 8 GPU per server design, and 1:4~6 attach ratio (800G) is commonly seen.

Exhibit 39: Ruijie's network solution: optical module attach rate at 1:4/ 1:6 for 2-/ 3-layer network (800G)

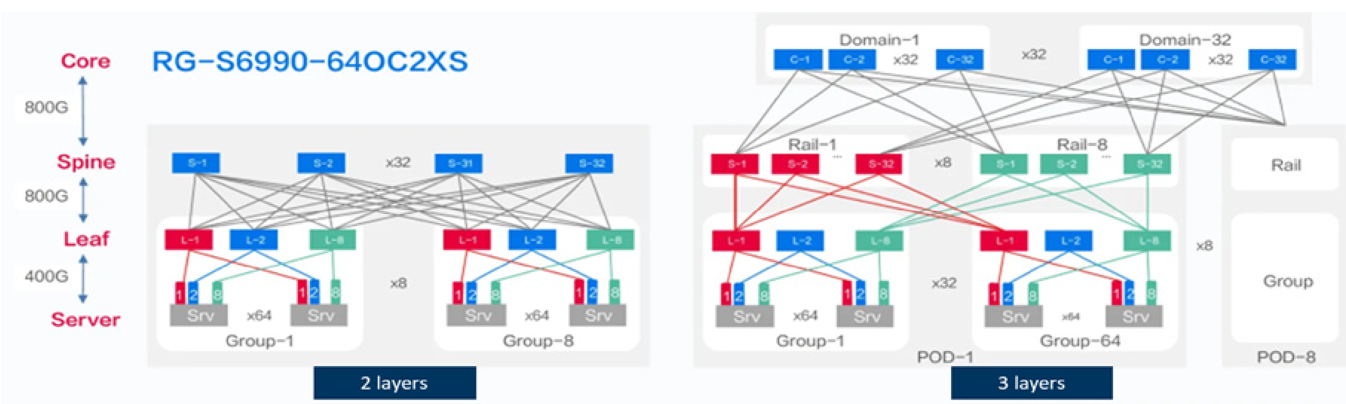
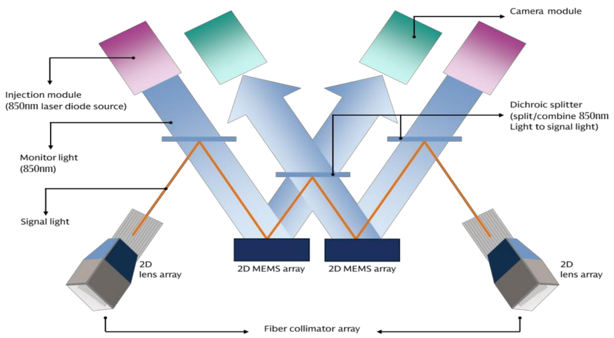


Exhibit from Ruijie

Source: Company data

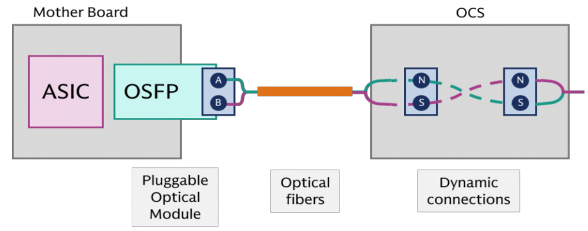
(13) Optical Circuit Switch: Achieving all optics networking

Exhibit 40: Google's Palomar OCS based on MEMS technology



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 41: Optical modules are not needed on OCS switch, while still needed on server motherboards



Source: Company data, Compiled by Goldman Sachs Global Investment Research

As more optical connections are adopted in data centers, OCS (Optical Circuit Switch) will be an alternative option. Compared to traditional data center switches, which require optical-electrical-optical transformation, the **OCS switch is completely based on optical signals**, which allows for higher bandwidth, power efficiency, and scalability. The OCS switch provides an analog light path from the input fiber to the output fiber, and it passes through 800G/ 1.6T/ 3.2T lights in the same way. Therefore, by deploying the OCS switch, AI data center does not need to replace their switch when upgrading to faster data rate, and a same OCS switch can support different data rate at the same time. This feature makes it an optimal solution for today's fast changing AI clusters. **Key progress:** (1) Innolight targets SiPh OCS in 2027, (2) Robotechnik announced that they obtained an order of " fully automated OCS (Optical Switch) packaging line" from its Europe customer. The order is worth EUR 7.7m, (3) Lumentum's optical circuit switches (OCS) backlog reached beyond $400 million in Feb 2026, (4) Coherent: per management, the company has engaged with over 10 customers on OCS as of Feb 2026. Shipments and backlog include 64x64 systems and 320x320 systems, and expected OCS revenue to grow sequentially in the coming quarters after Feb 2026.

Exhibit 42: The development timeline of OCS

Development timeline of OCS	
2015	**Google** launched the Apollo OCS project to develop the OCS switch
2023	**Google** announced TPU v4 is the first supercomputer to deploy OCS, with 4096 chips interconnected by 48 internally-developed OCS
2025	**Google's** TPU v7 SuperPod adopts OCS to interconnect 9,216 chips **OCP** announced new OCS project, with participants including **Lumenutm, iPronics, Google, Nvidia, Coherent, Microsoft**, etc.
2026	**Lumentum** announced that it's scaling rapidly to meet extraordinary customer demand that has already driven our backlog well beyond $400 million **Coherent** expects OCS revenue to ramp through this year and next, with over 10 customers engagements now

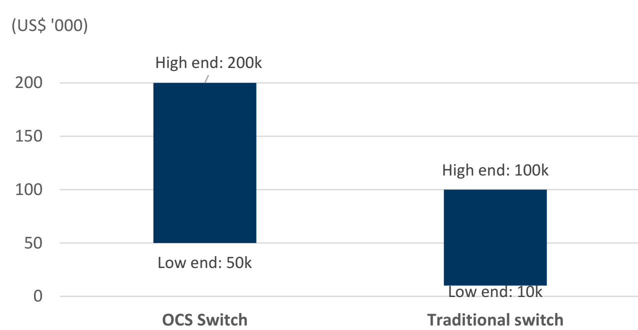
Source: Company data, Data compiled by Goldman Sachs Global Investment Research

Exhibit 43: OCS: major technology options

	MEMS	LC/LCoS	Piezo/ DLBS	SiPh
What does it mean	MEMS Mirror or Micro-electromechanical systems	Liquid crystal	Direct Light Beam-Steering	Silicon Photonics
How does it work	Control the deflection of the mirrors by applying voltage, thereby changing the propagation path of the light.	Beam deflection utilizing the electro-optic effect of liquid crystals and the cascading of crystal wedges.	Two collimator arrays are placed face to face to form a switch matrix. Electric field drive the the collimators to shift and tilt, aligning corresponding ports and achieve optical switching.	Constructing defined optical path matrix on a silicon-based chip, allowing optical signals to be transmitted along a predetermined path.
Advantages and Disadvantages	Matured solution with mass production track record	**Pros:** Higher reliability as there's no mechanical moving parts, low voltage and low power consumption **Cons:** switching time is slow	**Pros:** More reliable and Lower loss than MEMS **Cons:** hard to support very large port numbers	**Pros:** Fast switching time. Potential low cost for mass production **Cons:** High insertion loss
Progress	Mass production, now the major solutoin	Mass production	In qualification	In qualification
Switching time	Medium (<100ms)	Slow (>100ms)	Medium (<100ms)	Low (nanosecond)
Reliability	Low	High	High	High
Drive voltage	~ 100V	<= 10V	~ 10V	Low
Insertion Loss	Low (~ 3dB)	Low (~ 4dB)	Low (~ 2.5dB)	High (~ 6dB)
Crosstalk	Low	Low	High	High
Key players	Google, Lumentum, Accelink, Calient.AI **OCS switch designer: Googgle** (GOOGL), Lumentum (LITE), Calient (Private), Accelink (002281.SZ)	Coherent **OCS switch designer:** Coherent (COHR)	Huber+Suhner Polatis **OCS switch designer:** Huber+Suhner (HUBN.SW)	InnoLight, iPronics, Taclink **OCS switch designer:** Innolight (300308.SZ), iPronics (Private), Taclink (688205.SS)
Supply chain	**MEMS:** Sai MicroElectronics (300456.SZ), XDLK Microsystem (688582.SS) **VSCEL:** Lumentum (LITE), Coherent/Finisar (COHR) **FAU:** Corning (GLW) **Optical fiber cable:** Ezconn (6442.TW) **System ODM:** Advanced Fiber Resource (300620.SZ) **Equipment:** Robotechnik (300757.SZ) **Packaging:** Halma Plc (HLMA.L)	**Optical component:** Optowide (688195.SS) **Equipment:** Robotechnik (300757.SZ) **Packaging:** Halma Plc (HLMA.L)	**System ODM:** Luster (688400.SS) **Equipment:** Robotechnik (300757.SZ)	**SiPh chip:** HGTech (000988.SZ) **System ODM:** Taclink (688205.SS), Innolight (300308.SZ) **Equipment:** Robotechnik (300757.SZ)

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

Exhibit 44: ASP of OCS vs. traditional switch



As of Apr 2026

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

Exhibit 45: OCS switch by Accelink

Source: Company data

(14) Technology adoption: pace varies on infrastructure

Exhibit 46: Technology adoption by CSP

	Nvidia	Google	Microsoft	Meta	Amazon	Oracle	Chinese CSP
Optical module							
800G	√	√	√	√	√	√	√
1.6T	√	√	O (2027)	O (2026)	O (2027)	O (2027)	O
3.2T	O (2028)	O (2028)					
CPO							
Scale up	O			O			
Scale out	O	O		O			
OCS							
Scale up or scale out		√					

Note: √: adopted O: See progress in adoption

Source: Company data, Data compiled by Goldman Sachs Global Investment Research

While the networking technology migration is a certain trend, the pace of adoption varies depending on the clients' data center infrastructure readiness and their specific design needs. Key factors that affect technology migrations include: (1) **Depreciation and utilisation of older facilities.** If current generation capacities have not yet been fully depericiated, the financial pressure of moving quickly to the next generation can be significant. (2) **New infrastructure readiness.** Sometimes the technology migration is slowed by the construction time for new buildings, power grids and heat dissipation infrastructure. (3) **Waiting for cost reduction .** When a new technology is put into use, the cost can be substantially higher than in the later stage where it enters mass production. (4) **Uncertain technology direction.** When the technologies are still developing and there are multiple potential directions, heavy early investment could pose a risk in an evolving technology landscape.

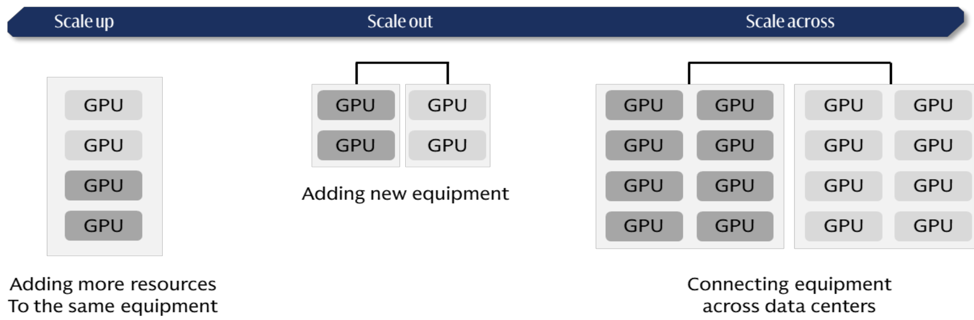
Appendix: Prysmian (PRY.MI, Buy): Largest global cable maker

Prysmian (PRY.MI, Buy, covered by Daniela Costa) Prysmian is the largest global cable maker focused primarily on electricity cables, with 8% of revenues from fiber and fiber optic cable sales. It is one of the largest manufacturers of raw fiber along with Corning, Sumitomo, Fujikura and others. Prysmian's Digital Solutions sales exposure is ~4% to raw fiber sold to other OEMs and ~96% to cables, of which Telecom Solutions account for ~66% and data centers ~16%, mainly exposed to long distance and intra campus connectivity. Within its Digital Solutions business, Prysmian has ~46% exposure to EMEA, ~40% to North America, ~10% to APAC, and ~4% to Latin America. In 2025, Prysmian acquired Channell, strengthening its positioning by adding fiber management systems, enclosures, and connectivity hardware, and enabling a more complete end to end offering alongside its cable portfolio.

We expect Prysmian to see strong pricing tailwinds from higher fiber prices, driven by data center demand. The company notes it has a full order book through 2026 from its Fiber customers and is seeing customers willing to sign long term framework agreements at current price levels. Prysmian's vertically integrated production capabilities—covering preform, fiber drawing, and cabling—allow it to benefit from tight market conditions, with the group producing around two-thirds of its fiber requirements in-house and outsourcing lower spec products. Given sustained demand, Prysmian is planning brownfield capacity expansions in fiber. Alongside its leading manufacturing footprint, the company continues to invest in next generation technologies, including hollow core fiber to reduce latency in high density environments and the first commercially available 160 micron bend insensitive fiber.

Appendix: Scale up vs. Sale out vs. Scale across

Exhibit 47: Illustration of scale up, scale out and scale across connections



Source: Company data, Goldman Sachs Global Investment Research

Given the increasing need for high speed AI computing, the industry has been trying to connect more GPUs to expand the size of AI clusters. There are three major ways of expansion: **(1) Scale up**: adding more GPUs and computing resources within the same piece of equipment, typically within the same server rack (e.g. Nvidia's Vera Rubin rack connects 72 GPUs in a rack); nowadays there are scale-up expansions that connect across racks, or the so-called supernodes, where the networking speed across racks are optimized to close to the connections within the same rack; **(2) Scale out:** adding more equipment and connecting them through switching technologies, a traditional way of network expansion. Nowadays, AI clusters support scale out connections of 100k+ GPUs; **(3) Scale across:** connecting servers across data centers in different locations; Nvidia introduced their solutions for scale-across networking via in-house Ethernet switch and NIC (network interface controller) products.

Appendix: Closed vs. Open ecosystems

Nvidia is also a participant of ESUN although its the major beneficiary of closed scale-up ecosystem.

There is an ongoing competition of closed ecosystem and open ecosystem for networking in data centers. In scale-up networking, it is dominated by Nvidia's closed ecosystem, in which Nvidia design its own switch ASICs and switch equipment and delivery "full rack" designs such as Vera Rubin racks. However, the establishment of ESUN (Ethernet for Scale-Up Networking) in Oct 2025, OCP marked a step forward of the open ecosystem entering the scale up domain; the goal of ESUN is to adopt the Ethernet technology to scale-up applications. UALink is another open networking initiative focusing on GPU-GPU scale-up networking, and has announced 200G 1.0 Specification in May 2025. **In scale-out networking**, Nvidia's infiniBand (closed ecosystem) is challenging the dominance of Ethernet. InfiniBand comes with higher performance including lower latency and higher bandwidth, while Ethernet remains the cost effective and compatible choice. In order to upgrade the Ethernet performance, the UEC (Ultra Ethernet Consortium) was established in Aug 2023 with the goal of optimizing Ethernet for AI and HPC application, and the consortium announced the 1.0

specification in June 2025.

Exhibit 48: Scale up networking: Closed vs. Open ecosystems

Scale up networking	Closed ecosystem			Open ecosystem	
	NVIDIA			UALink	Ethernet for Scale-up Networking (ESUN)
Technology	**Nvlink 5.0**	**Nvlink 6.0**	**Nvlink 7.0**	**UALink 1.0**	**ESUN (Ethernet for Scale-Up Networking)/ SUE-T**
Major players	Nvidia	Nvidia	Nvidia	**Promoters**: Alibaba, AWS, AMD, Apple, Astera Labs, CISCO, Google, HPE, Intel, Meta, Microsoft, Synopsys	AMD, Arista, ARM, Broadcom, CISCO, HPE, Marvell, Meta, Microsoft, Nvidia, OpenAI, Oracle
Year	2024	2026	2027	2025	2025
Network base	/	/	/	Physical Layer: Ethernet PHY	Ethernet
High speed I/O	**224 Gbps**	**400 Gbps**	**TBA**	**224 Gbps**	**TBA**
Max. scalability	576 GPUs	TBA	TBA	1024 GPUs	TBA
Openess	Closed (Nvidia)	Closed (Nvidia)	Closed (Nvidia)	Open	Open
Example	Nvidia Blackwell Racks	Nvidia Rubin Racks	Rubin ultra Racks	AMD Helios Racks	-

Source: Data compiled by Goldman Sachs Global Investment Research, Company data

Exhibit 49: Scale out networking: Closed vs. Open ecosystems

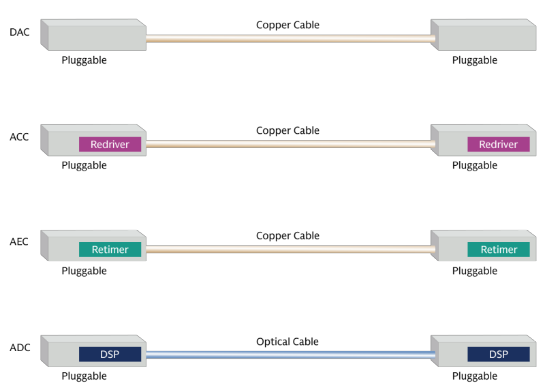
Scale out networking	Closed ecosystem			Open ecosystem	
	InfiniBand Trade Association / NVIDIA			RoCE	Ultra Ethernet Consortium
Technology	**InfiniBand NDR**	**InfiniBand XDR**	**InfiniBand GDR**	**RoCE v2 (RDMA over Converged Ethernet)**	**UEC (Ultra Ethernet) 1.0**
Major players	Nvidia (Mellanox)	Nvidia (Mellanox)	Nvidia (Mellanox)	**Steering Committee of IBTA**: HPE, IBM, Intel, Nvidia (Mellanox)	**Steering Members:** AMD, Arista, Broadcom, CISCO, Eviden, HPE, Intel, Meta, Microsoft, Oracle
Year	2022	2025	2027-2028 (GSe)	2014-2025	2025
Network base	/	/	/	Ethernet with Data Center Bridging	Ethernet
Single Lane (1x)	100 Gbps	200 Gbps	400 Gbps	200 Gbps (Ethernet in 2025)	200 Gbps (Ethernet in 2025)
Port Rate (8x)	800 Gbps	1600 Gbps	3200 Gbps	1600 Gbps (Ethernet in 2025)	1600 Gbps (Ethernet in 2025)
Openess	Closed (Nvidia)	Closed (Nvidia)	Closed (Nvidia)	Open	Open
Latency	**< 2 µs**	**< 2 µs**	**< 2 µs**	**< 5 µs**	**< 2 µs**
TCO		**1.5-2.5x higher than RoCE**		**Medium cost**	**Lower cost**
Supported switch	Quantum-2 InfiniBand Switch	Quantum-X800 InfiniBand Switch	TBA	Ethernet Swith of Arista, Juniper, Cisco, HPE, etc; NVIDIA Spectrum-4 Ethernet Switch	Ethernet Swith of Arista, Juniper, Cisco, HPE, etc;
Example	Nvidia Blackwell Racks	Nvidia Blackwell Racks	Nvidia Rubin Racks	Meta Llama 3 Cluster (with 24k H100 GPUs)	TBA

Source: Data compiled by Goldman Sachs Global Investment Research, Company data

Appendix: Illustration of different connection products

Exhibit 50: DAC/ ACC/ AEC/ ADC: widely used in scale up and scale out connections

Copper (DAC/ AAC/ AEC) vs. Optical cables (ADC)

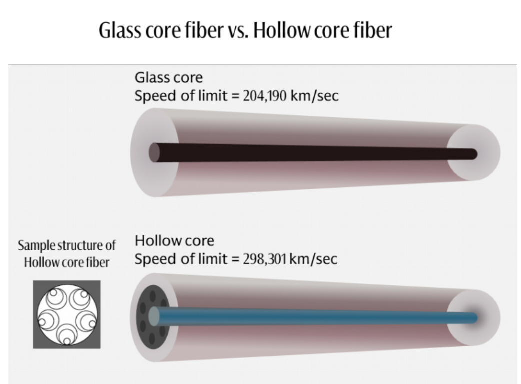


Micron

Source: Company data

Exhibit 51: Hollow core fiber: potentially for scale-across connections

Hollow core fiber support extra low latency comparing to traditional fiber



Source: Company data

Disclosure Appendix

Reg AC

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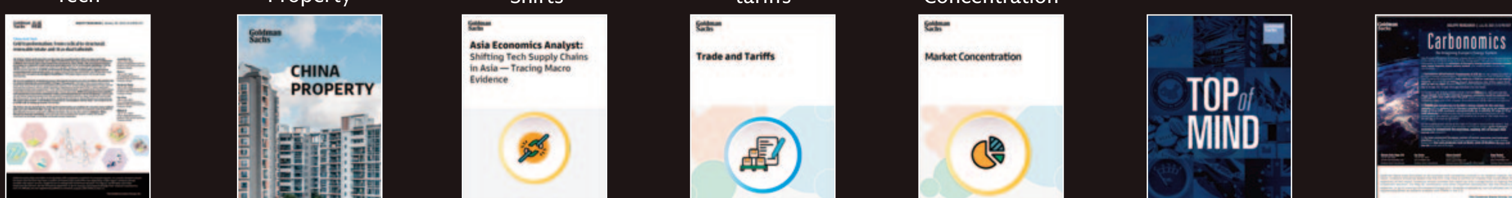

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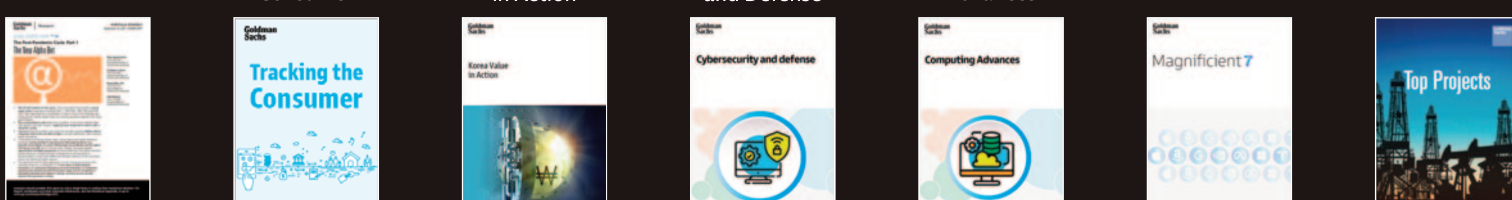

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