Architecting Near-Packaged Optics for AI Datacenters:

Key Technology Choices and Trade-offs



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NPO: Serviceable CPO with Internal Laser Option

Re-timed pluggable



1 SerDes + 1 DSP

~15

pJ/bit link power

Host SerDes plus a DSP in the module

LRO



1 SerDes + ½ DSP

~10

pJ/bit link power

DSP on the Tx side only

LPO / NPO / CPO



1 SerDes

~6

pJ/bit link power

Host SerDes only; shorter channel than LPO

Integrated optics with die-to-die interfaces



0 SerDes

< 4

pJ/bit link power

Optics on the die; years from volume

	Pluggable	NPO	CPO	CIO
Service model	Hot-swap module	**Replaceable engine**	Laser externalized	Package-level

NPO: Same energy class as CPO. Unlike CPO, the optical engine stays a part you can replace

Three coupled choices define an NPO engine

Modulator

- InP (EAM / MZM)
- TFLN (MZM)
- SiPh (MZM / MRM)

Laser

- Monolithic (InP)
- Integrated on PIC
- In-package, near OE
- External laser source

Packaging & Assembly

- Host attach
- OE socket
- Thermal path
- Assembly

Each choice trades **Performance** · **Thermal management** · **Serviceability**

No modulator wins on every axis

Best | Good | Fair | Weakest

Criterion	InP EML / EAM	InP MZM	SiPh MZM	SiPh MRM	TFLN MZM
Drive voltage Vdrive (EAM, MRM), Vπ (MZM)	Low	Low	High	Lowest	Low
EO bandwidth Headroom at 400G/lane	High	High	RC-limited	Moderate	Highest
Length Modulator section	Short	Moderate	Long	Smallest	Longest
Loss Incl. coupling	Moderate	Moderate	Higher	Moderate	Lowest
Thermal sensitivity Drift and tuning needs	May need TEC	May need TEC	Near-athermal	Active tuning	Excellent

TFLN leads on speed, loss and stability; InP pairs low drive and high speed with a native laser; silicon trades Vπ/thermal control for scale.

Laser Placement and Trade-offs

Distance from modulator →	Internal (Monolithic)	Internal (Integrated on PIC)	Internal (In-package)	External source (ELSFP)
Optical budget	lowest laser-PIC coupling loss -- 0.25dB loss laser-to-mod	One bonded interface; 0.5~1dB loss laser-to-mod	Micro-optic coupling; 1.5 dB loss laser-to-mod	Fiber and connectors; highest loss and laser power – 2 dB loss ELSFP-to-mod
Thermal	Laser in the engine heat zone	Laser in the engine heat zone	Laser in the engine heat zone	Laser at the cooler front panel
Service	Replace the engine	Replace the engine	Replace the engine	Replace the laser in the field
Laser RIN	Good	Good	Great	Great
Manufacturing	Single InP wafer	Two platforms; yield compounds	Known-good, burned-in laser die	Shared source (4-16 lanes); PM fiber handling

Internal lasers offer ***simpler system design***, ***less reliance on UHPL***, ***remove PM fibers***, and help with ***front panel ELSFP density*** specially for 200T switch generation

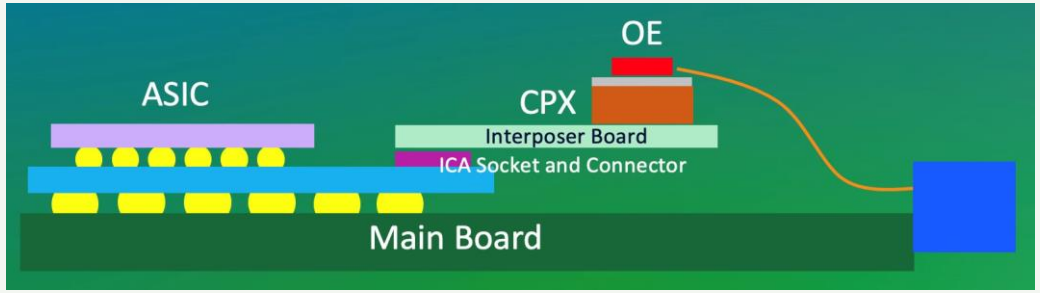
Packaging sets the power, thermal and service model

Host Attach

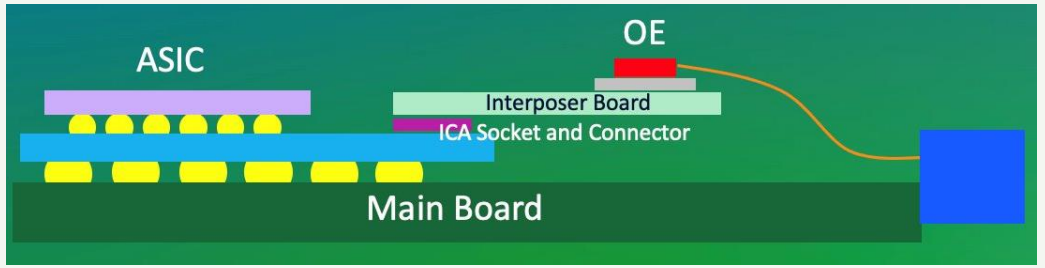
- ***OE on the ASIC substrate (connectorized)***
- ***OE on the ASIC main board***
- ***OE on paddle/interposer card***
  - ✓ Metal-contact compression LGA
  - ✓ Elastomer membrane with metal contacts
  - ✓ Conductive elastomer (aligned particle columns, conductive polymer)

OE Socket

- ***2-piece connector***: CPX Type 1/2 (MSA) and other proprietary approaches



- ***Soldered down to paddle card***



Thermal Path

Share the ASIC cold plate; keep lasers cool.

A cold plate works only if the heat path is designed in.

Assembly

Known-good-die lasers and PICs; wafer-level test.

Passive alignment and automation for volume.

Manufacturing scale and performance will pick the winners

A design that can't be built at hyperscaler volume won’t have a chance.

→ Customers are asking for ~10× InP volume by the end of the decade.

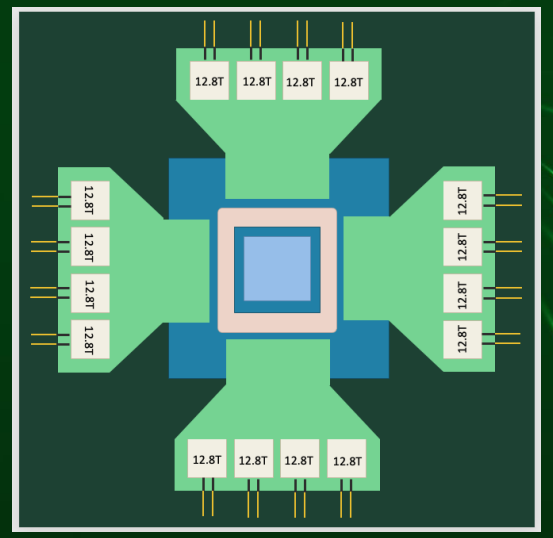
→ Nokia is investing in 6-inch manufacturing to significantly scale capacity.

Nokia: 6-inch InP platform

LASERS: Monolithic · Internal · External

MODULATORS: InP · SiPh · TFLN

3-inch · Sunnyvale	6-inch · San Jose	6-inch · Arizona
1st InP fab	2nd InP fab · New	3rd InP fab · New



Nokia DC Switch with NPO Engines

Takeaways

1. NPO sits in the same energy class as CPO, with the optics outside the ASIC package: the near-term, serviceable path.

2. A replaceable engine outside the host heat zone makes on-engine lasers viable again; external lasers remain the hedge for the hottest, densest scenarios.

3. Laser choice and modulator choice are related: InP pairs natively with monolithic lasers; TFLN and SiPh need integrated/in-package/external sources.

4. The winners will be the engines that can be packaged, cooled and built at volume, not just the best-performing devices.

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