Faster by Design

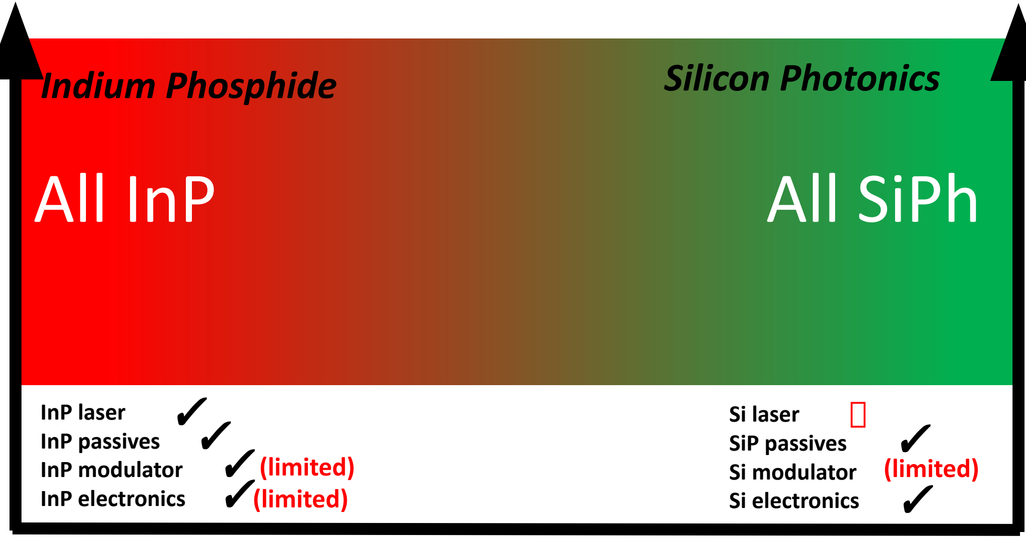
Hybrid photonic integration roadmap

Michael Lebby, CEO
Lightwave Logic (NASDAQ:LWLG)

Hybrid PIC…

Fiber communications have 2 incumbent PICs, however…

Incumbent *Incumbent*



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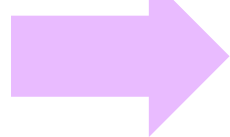


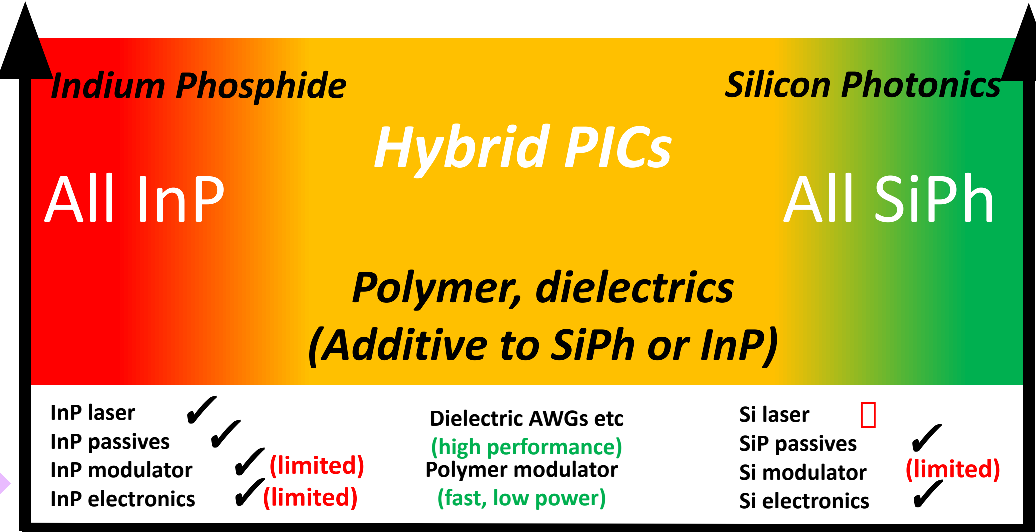
Limited attributes

Incumbent technologies can't do everything monolithically…

Source: LWLG

Hybrid PICs increase performance…

New hybrid PICs



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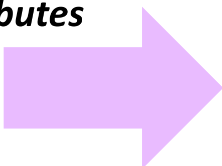

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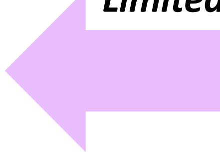


Hybrid solutions

Hybrid PICs can boost performance of PICs

Source: LWLG

Trend towards hybrid PICs…

- PIC incumbent platforms:
  - InP (Indium Phosphide) e.g. Hybrid PIC InP + Si ICs
  - SiPh (Silicon photonics) e.g. Hybrid PIC SiPh + InP Laser
- ***New platforms for Hybrid PICs***
  - *Polymers (modulators)*
  - *Dielectrics (passives)*
  - *Silica (passives)*
  - *Glass (passives)*
  - *Thin Film Lithium Niobate (TFLN) (modulators)*
  - *Metal/plasmonic, (modulators)*
  - *Barium titanate (BTO) (modulators)*
  - *Germanium (detectors)*
  - *Gallium Nitride (GaN) (LEDs)*
  - ***Many others…***

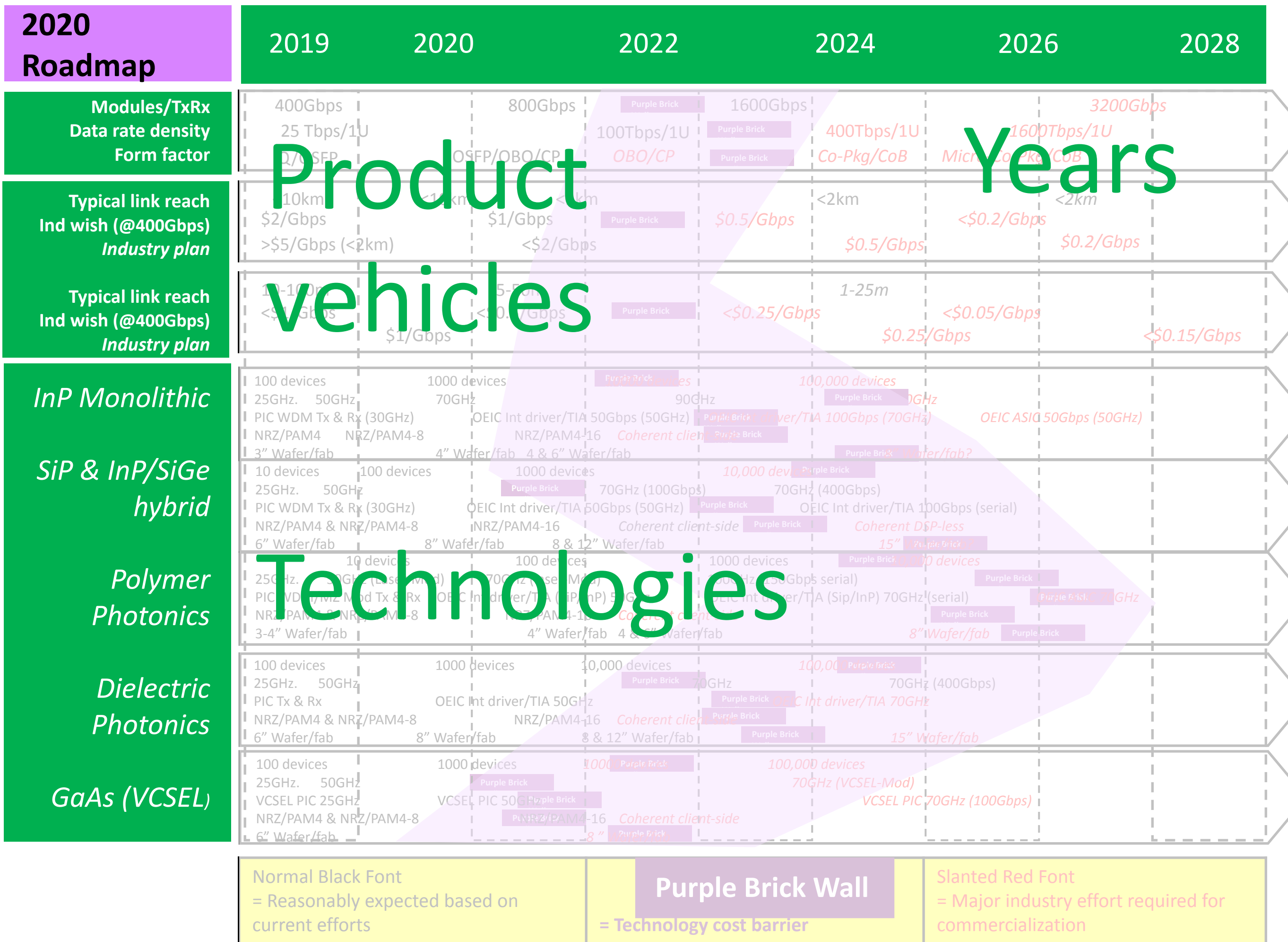
Mix and match to optimize the best performance…

Source: LWLG

We need roadmaps:
Just like Nostradamus…

Roadmap 2020

LIGHTWAVE



Tough to design >1600Gbps+ TxRx modules…

Tough to design >70GHz bandwidth devices…

Some technologies have higher performance….

How to scale PIC integration?

Simple metrics

Sources: LWLG, iNEMI, AIM Photonics, Photon Delta

2020 Roadmap

	2019	2020	2022	2024	2026	2028
Modules/TxRx Data rate density Form factor	400Gbps 25 Tbps/1U Q/OSFP	800Gbps OSFP/OBO/CP	1600Gbps 100Tbps/1U OBO/CP	400Tbps/1U Co-Pkg/CoB	3200Gbps 1600Tbps/1U Micro-Co-Pkg/CoB	
Typical link reach Ind wish (@400Gbps) *Industry plan*	<10km $2/Gbps >$5/Gbps (<2km)	<10km $1/Gbps <$2/Gbps	<2km $0.5/Gbps	<2km <$0.2/Gbps	<2km $0.2/Gbps	
Typical link reach Ind wish (@400Gbps) *Industry plan*	10-100m <$1/Gbps $1/Gbps	5-50m <$0.5/Gbps	<$0.25/Gbps	1-25m <$0.05/Gbps $0.25/Gbps	<$0.15/Gbps	
InP Monolithic	100 devices 25GHz. 50GHz	1000 devices 70GHz	90GHz	OEIC ASIC 50Gbps (50GHz)		
SiP & InP/SiGe hybrid	10 devices 25GHz. 50GHz PIC WDM Tx & Rx (30GHz)	100 devices OEIC Int driver/TIA 50Gbps (50GHz) NRZ/PAM4-16	1000 devices 70GHz 100Gbps) 8 & 12" Wafer/fab			
Polymer Photonics	PIC WDM/MZ Mod Tx & Rx NRZ/PAM4 & NRZ/PAM4-8 3-4" Wafer/fab	100 devices 70GHz (laser-Mod) OEIC Int driver/TIA (SiP/InP) 50GHz NRZ/PAM4-16 4" Wafer/fab	1000 devices 100GHz (150Gbps serial) Coherent client-side			
Dielectric Photonics	NRZ/PAM4 & NRZ/PAM4-8 6" Wafer/fab	8" Wafer/fab	10,000 devices 8 & 12" Wafer/fab	70GHz (400Gbps) OEIC Int driver/TIA 70GHz		
GaAs (VCSEL)	100 devices 25GHz. 50GHz VCSEL PIC 25GHz NRZ/PAM4 & NRZ/PAM4-8	1000 devices VCSEL PIC 50GHz	Coherent client-side	VCSEL PIC 70GHz (100Gbps)		

Normal R&D funding

Major investment in R&D to achieve goals

Normal Black Font = Reasonably expected based on current efforts	**Purple Brick Wall** = Technology cost barrier	Slanted Red Font = Major industry effort required for commercialization

Tough to design >1600Gbps+ TxRx modules…

Tough to design >70GHz bandwidth devices…

Some technologies have higher performance….

How to scale PIC integration?

Red means major industry efforts needed for commercialization

Sources: LWLG, iNEMI, AIM Photonics, Photon Delta

LIGHTWAVE

2020 Roadmap	2019	2020	2022	2024	2026	2028
Modules/TxRx Data rate density Form factor	400Gbps 25 Tbps/1U Q/OSFP	800Gbps OSFP/OBO/CP	1600Gbps 100Tbps/1U OBO/CP	400Tbps/1U Co-Pkg/CoB	3200Gbps 1600Tbps/1U Micro-Co-Pkg/CoB	
Typical link reach Ind wish (@400Gbps) *Industry plan*	<10km $2/Gbps >$5/Gbps (<2km)	<10km $1/Gbps <$2/Gbps	<2km	<2km <$0.2/Gbps $0.5/Gbps	<2km $0.2/Gbps	
Typical link reach Ind wish (@400Gbps) *Industry plan*	10-100m <$1/Gbps	$1/Gbps 5-50m <$0.5/Gbps	<$0.25/Gbps	1-25m <$0.05/Gbps $0.25/Gbps	<$0.15/Gbps	

InP Monolithic · SiP & InP/SiGe hybrid · Polymer Photonics · Dielectric Photonics · GaAs (VCSEL)

Purple brick wall = Technology cost barrier

Normal Black Font = Reasonably expected based on current efforts

Purple Brick Wall = Technology cost barrier

Slanted Red Font = Major industry effort required for commercialization

Tough to design >1600Gbps+ TxRx modules…

Tough to design >70GHz bandwidth devices…

Some technologies have higher performance….

How to scale PIC integration?

We may have photonics technology □ but not at a cost for commercialization…

Sources: LWLG, iNEMI, AIM Photonics, Photon Delta

Roadmap 2020 (OLD)

Warning - Eye-chart!

Don’t try and read it – zoom soon

(can be found at www.lightwavelogic.com)

2020 PIC roadmap (datacom)

2020 Roadmap — 2019 | 2020 | 2022 | 2024 | 2026 | 2028

Modules/TxRx, Data rate density, Form factor
- 400Gbps — 800Gbps — 1600Gbps — *3200Gbps*
- 25 Tbps/1U — 100Tbps/1U — *400Tbps/1U* — *1600Tbps/1U*
- Q/OSFP — OSFP/OBO/CP — *OBO/CP* — *Co-Pkg/CoB* — *Micro-Co-Pkg/CoB*

Typical link reach, Ind wish (@400Gbps), *Industry plan*
- <10km — <10km — <2km — <2km — <2km
- $2/Gbps — $1/Gbps — *$0.5/Gbps* — *<$0.2/Gbps*
- >$5/Gbps (<2km) — <$2/Gbps — *$0.5/Gbps* — *$0.2/Gbps*

Typical link reach, Ind wish (@400Gbps), *Industry plan*
- 10-100m — 5-50m — 1-25m
- <$1/Gbps — <$0.5/Gbps — *<$0.25/Gbps* — *<$0.05/Gbps*
- $1/Gbps — *$0.25/Gbps* — *<$0.15/Gbps*

InP Monolithic
- 100 devices — 1000 devices — *10,000 devices* — *100,000 devices*
- 25GHz. 50GHz — 70GHz — 90GHz — *100GHz*
- PIC WDM Tx & Rx (30GHz) — OEIC Int driver/TIA 50Gbps (50GHz) — *OEIC Int driver/TIA 100Gbps (70GHz)* — *OEIC ASIC 50Gbps (50GHz)*
- NRZ/PAM4 — NRZ/PAM4-8 — NRZ/PAM4-16 — *Coherent client-side*
- 3” Wafer/fab — 4” Wafer/fab — 4 & 6” Wafer/fab — *8” Wafer/fab?*

SiP & InP/SiGe hybrid
- 10 devices — 100 devices — 1000 devices — *10,000 devices*
- 25GHz. 50GHz — 70GHz (100Gbps) — 70GHz (400Gbps)
- PIC WDM Tx & Rx (30GHz) — OEIC Int driver/TIA 50Gbps (50GHz) — OEIC Int driver/TIA 100Gbps (serial)
- NRZ/PAM4 & NRZ/PAM4-8 — NRZ/PAM4-16 — *Coherent client-side* — *Coherent DSP-less*
- 6” Wafer/fab — 8” Wafer/fab — 8 & 12” Wafer/fab — *15” Wafer/fab?*

Polymer Photonics
- 10 devices — 100 devices — 1000 devices — *10,000 devices*
- 25GHz. 50GHz (Laser-Mod) — 70GHz (laser-Mod) — 100GHz (150Gbps serial)
- PIC WDM/MZ Mod Tx & Rx — OEIC Int driver/TIA (SiP/InP) 50GHz — OEIC Int driver/TIA (Sip/InP) 70GHz (serial) — *OEIC ASIC 70GHz*
- NRZ/PAM4 & NRZ/PAM4-8 — NRZ/PAM4-16 — *Coherent client-side*
- 3-4” Wafer/fab — 4” Wafer/fab — 4 & 6” Wafer/fab — *8” Wafer/fab*

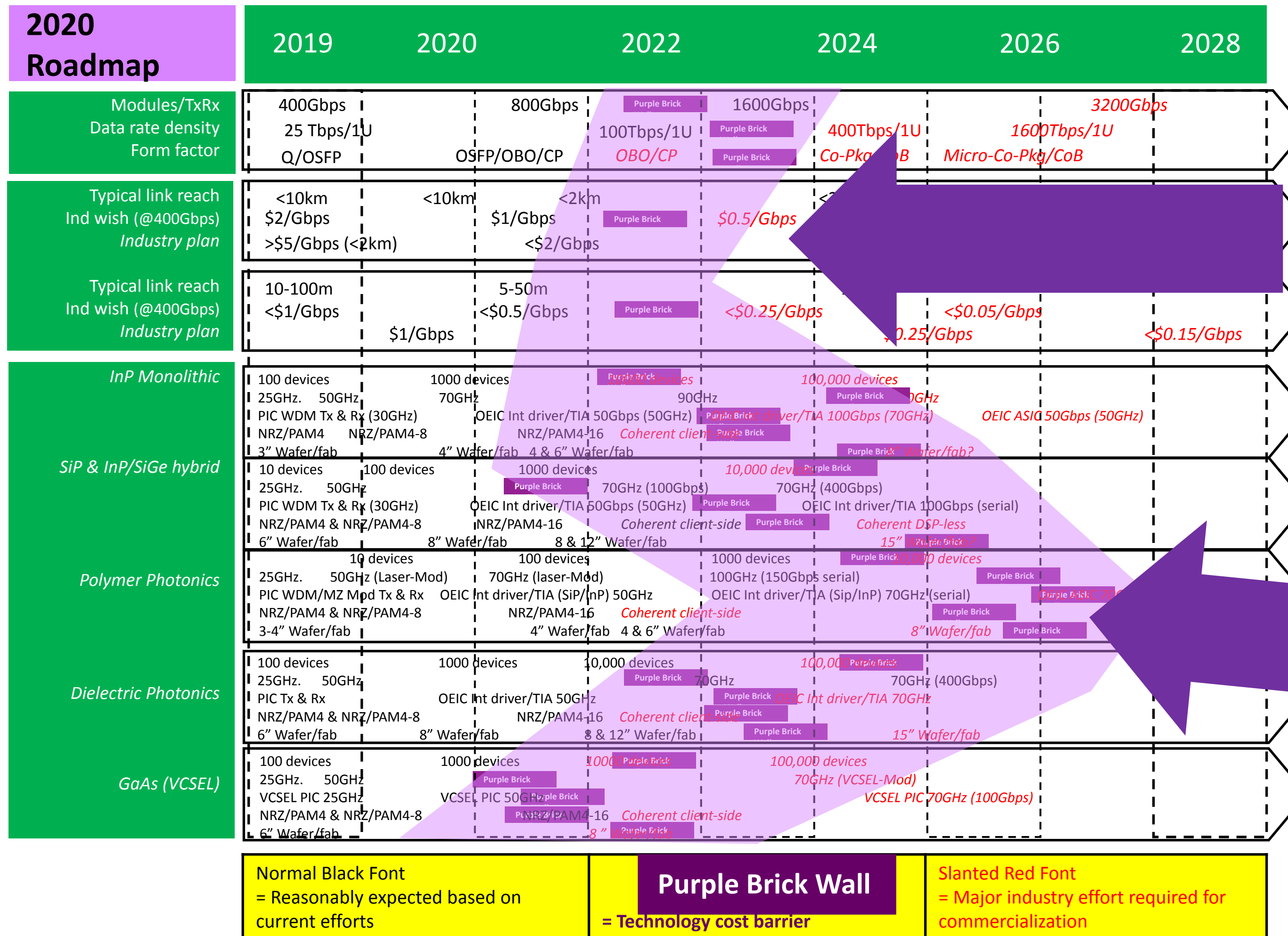
Dielectric Photonics
- 100 devices — 1000 devices — 10,000 devices — *100,000 devices*
- 25GHz. 50GHz — 70GHz — 70GHz (400Gbps)
- PIC Tx & Rx — OEIC Int driver/TIA 50GHz — *OEIC Int driver/TIA 70GHz*
- NRZ/PAM4 & NRZ/PAM4-8 — NRZ/PAM4-16 — *Coherent client-side*
- 6” Wafer/fab — 8” Wafer/fab — 8 & 12” Wafer/fab — *15” Wafer/fab*

GaAs (VCSEL)
- 100 devices — 1000 devices — *10000 devices* — *100,000 devices*
- 25GHz. 50GHz — *70GHz (VCSEL-Mod)*
- VCSEL PIC 25GHz — VCSEL PIC 50GHz — *VCSEL PIC 70GHz (100Gbps)*
- NRZ/PAM4 & NRZ/PAM4-8 — NRZ/PAM4-16 — *Coherent client-side*
- 6” Wafer/fab — *8” Wafer/fab*

Normal Black Font = Reasonably expected based on current efforts	**Purple Brick Wall** = Technology cost barrier	*Slanted Red Font* = Major industry effort required for commercialization

Years vs product vehicles vs technologies

Sources: LWLG, iNEMI, AIM Photonics, Photon Delta



Tough to design >1600Gbps TxRx modules…

Tough to design >70GHz bandwidth devices…

Some technologies have higher performance….

Where we penetrate the 'Purple Brick Wall'?

Sources: LWLG, iNEMI, AIM Photonics, Photon Delta

New!

Draft roadmaps 2022

Hybrid PIC roadmap - datacom

2022 Roadmap — 2022 | 2024 | 2026 | 2028 | 2030……………..2040

Modules/TxRx / Data rate density / Form factor
- 800Gbps | 1600Gbps | Purple Brick Wall | *3200Gbps* | *6.4Tbps* | *12.8Tbps* | *25.2Tbps* | *50.4Tbps*
- 25 Tbps/1U | 50Tbps/1U | 100Tbps/1U | Purple Brick Wall | *400Tbps/1U* | *800Tbps/1U*
- Q/OSFP | OSFP/OBO/CP | OSFP/OBO/CP | Purple Brick Wall | *Micro-OSFP/OBO/CP*

Typical link reach / Ind wish (@800Gbps) / *Industry plan*
- <10km | <10km | <2km | <2km | *<2km*
- <$1/Gbps | $0.5/Gbps | Purple Brick Wall | *$0.25/Gbps* | *<$0.1/Gbps*
- $1-5/Gbps (<2km) | <$1/Gbps | Purple Brick Wall | *<$0.5/Gbps* | *<$0.2/Gbps* | *<$0.1/Gbps*

Typical link reach / Ind wish (@800Gbps) / *Industry plan*
- 10-100m | 5-100m | *1-100m*
- <$0.5/Gbps | <$0.25/Gbps | Purple Brick Wall | *<$0.1/Gbps* | *<$0.05/Gbps*
- $1-3/Gbps | <$1/Gbps | <$0.5/Gbps | Purple Brick Wall | *$0.25/Gbps* | *<$0.15/Gbps*

ACTIVE PLATFORM

Silicon Photonics – Modulator
- TW carrier inj | TW carrier inj | Micro Ring resonator | *Micro Ring resonator*
- 25-35GHz (4-6V) | 35GHz (3-6V) | 50GHz (2-6V) | Purple Brick Wall | *70GHz (2-6V)*

Indium Phosphide – Laser/Modulator
- PIC DD/Coherent DFB/DBR/SOA 1310/1550nm | OEIC Tx/Rx DD/Coh with MSI | OEIC Tx/Rx DD/Coh with LSI
- 30-40GHz (1-4V) | 35-50GHz (1-5V) | 50GHz (2-8V) | Purple Brick Wall | *80GHz (3-10V)*

EO Polymer – Modulator
- Slot waveguide 1310/1550nm | Integrated PIC slot W/G 1310/1550nm
- 70GHz (<1V) | 100GHz (<0.5V) | 110GHz (<0.5) | Purple Brick Wall | *150GHz (<1V)* | *170GHz*

Metal/plasmonic EO polymer – Modulator
- Slot L/E PIC 1310/1550nm | Coh/DD slot L/E PIC 1310/1550nm
- 100GHz (5-10V) | 150GHz (3-8V) | 200GHz (1-5V) | Purple Brick Wall | *300GHz (1-3V)* | *400GHz*

BTO – Modulator
- Integrated with SiPh/CMOS | Integrated PIC with CMOS
- 20-30GHz | 30-40GHz | Purple Brick Wall | *50GHz* | *70GHz*

TFLN – Modulator
- Multi-channel array | Integrated PIC with SiPh | Integrated PIC with CMOS
- 50GHz (3-8V) | 70GHz (2-5V) | 90GHz (2-5V) | Purple Brick Wall | *100GHz*

PASSIVE PLATFORM

Silicon Photonics – WG/SSC/Mux/Coupler
- Coherent/DD PIC w/Mux/SSC/PD/GC + LD source | SSI OEIC IC+SiPh w/LD/MRR | MSI OEIC IC+SiPh + LD/MRR
- 30-40GHz | 50GHz | Purple Brick Wall | *70GHz* | *80GHz*

Dielectric/Glass/Silica – WG/SSC/Mux/Coupler
- PIC w/Mux/SSC/PD/GC + LD source | SSI PIC with SiPh w/LD/Hybrid modulator | MSI PIC with SiPh w/LD/Hybrid modulator
- 30-40GHz | 50GHz | 70GHz | Purple Brick Wall | *100GHz* | *120GHz*

InP – WG/SSC/Mux/Coupler
- Coherent/DD PIC w/Mux/SSC/PD/GC + LD source | SSI OEIC w/Hybrid modulator | MSI OEIC w/Hybrid modulator
- 30-40GHz | 50GHz | 70GHz | Purple Brick Wall | *100GHz* | *120GHz*

Polymer – WG/SSC/Mux/Coupler
- Integrated PCB/Interposer w/Mux/SSC/PD/GC + LD source | PCB/Interposer w/Mux/SSC/PD/GC w/LD/Hybrid modulator
- 30-40GHz | 50GHz | 70GHz | Purple Brick Wall | *80GHz* | *90GHz*

Normal Black Font = Reasonably expected based on current efforts	**Purple Brick Wall** = Technology cost barrier	*Slanted Red Font* = Major industry effort required for commercialization

Sources: LWLG, iNEMI, AIM Photonics, Photon Delta

Hybrid PIC roadmap - datacom

2022 Roadmap	2022	2024	2026	2028	2030…………….2040
Modules/TxRx Data rate density Form factor	800Gbps 25 Tbps/1U Q/OSFP	OSFP/OBO/CP	1600Gbps *Purple Brick Wall* *3200Gbps* *6.4Tbps* 50Tbps/1U 100Tbps/1U *Purple Brick Wall* *400Tbps/1U* OSFP/OBO/CP *Purple Brick Wall* *Micro-OSFP/OBO/CP*	*12.8Tbps* *25.2Tbps*	*50.4Tbps* *800Tbps/1U*
Typical link reach Ind wish (@800Gbps) *Industry plan*	<10km <$1/Gbps $1-5/Gbps (<2km)	<10km	<2km $0.5/Gbps *Purple Brick Wall* *$0.25/Gbps* <$1/Gbps *Purple Brick Wall* *<$0.5/Gbps*	<2km *<$0.2/Gbps*	*<2km* *<$0.1/Gbps* *<$0.1/Gbps*
Typical link reach Ind wish (@800Gbps) *Industry plan*	10-100m <$0.5/Gbps $1-3/Gbps	<$1/Gbps	5-100m <$0.25/Gbps *Purple Brick Wall* *<$0.1/Gbps* <$0.5/Gbps *Purple Brick Wall* *$0.25/Gbps*	*1-100m* *<$0.05/Gbps* *<$0.15/Gbps*	

ACTIVE PLATFORM
Silicon Photonics — *Modulator*: TW carrier inj 25-35GHz (4-6V); TW carrier inj 35GHz (3-6V); Micro Ring resonator 50GHz (2-6V) *Purple Brick Wall*; *Micro Ring resonator 70GHz (2-6V)*
Indium Phosphide — *Laser/Modulator*: PIC DD/Coherent DFB/DBR/SOA 1310/1550nm 30-40GHz (1-4V); 35-50GHz (1-…); OEIC Tx/Rx DD/Coh with MSI; OEIC Tx/Rx DD/Coh with LSI
EO Polymer — *Modulator*: Slot waveguide 1310/1550nm 70GHz (<1V); Integrated PIC slot W/G 1310/1550nm 100GHz (<0.5V); 110GHz (<0.5); *Purple Brick Wall*; *150GHz (<1V)*; *170GHz*
Metal/plasmonic EO polymer — *Modulator*: Slot L/E PIC 1310/1550nm 100GHz (5-10V); 150GHz (3-8V); Coh/DD slot L/E PIC 1310/1550nm 200GHz (1-5V); *Purple Brick Wall*; *300GHz (<3V)*; *400GHz*
BTO — *Modulator*: Integrated with SiPh/CMOS 20-30GHz; 30-40GHz; Integrated PIC with CMOS; *Purple Brick Wall*; *50GHz*; *70GHz*
TFLN — *Modulator*: Multi-channel array 50GHz (3-8V); Integrated PIC with SiPh 70GHz (2-5V); Integrated PIC with CMOS 90GHz (2-5V); *Purple Brick Wall*; *100GHz*

PASSIVE PLATFORM
Silicon Photonics — *WG/SSC/Mux/Coupler*: Coherent/DD PIC w/Mux/SSC/PD/GC + LD source 30-40GHz; 50GHz; *Purple Brick Wall*; SSI OEIC IC+SiPh w/LD/MRR *70GHz*; MSI OEIC IC+SiPh + LD/MRR *80GHz*
Dielectric/Glass/Silica — *WG/SSC/Mux/Coupler*: PIC w/Mux/SSC/PD/GC + LD source 30-40GHz; 50GHz; SSI PIC with SiPh w/LD/Hybrid modulator 70GHz; *Purple Brick Wall*; *100GHz*; MSI PIC with SiPh w/LD/Hybrid modulator *120GHz*
InP — *WG/SSC/Mux/Coupler*: Coherent/DD PIC w/Mux/SSC/PD/GC + LD source 30-40GHz; 50GHz; 70GHz; SSI OEIC w/Hybrid modulator *Purple Brick Wall* *100GHz*; MSI OEIC w/Hybrid modulator *120GHz*
Polymer — *WG/SSC/Mux/Coupler*: Integrated PCB/Interposer w/Mux/SSC/PD/GC + LD source 30-40GHz; 50GHz; 70GHz; *Purple Brick Wall*; PCB/Interposer w/Mux/SSC/PD/GC w/LD/Hybrid modulator *80GHz*; *90GHz*

Enlarged next slide

Normal Black Font = Reasonably expected based on current efforts	**Purple Brick Wall** = Technology cost barrier	*Slanted Red Font = Major industry effort required for commercialization*

Sources: LWLG, iNEMI, AIM Photonics, Photon Delta

Hybrid PIC roadmap - datacom

	2026		2028		2030....
1600Gbps	Purple Brick Wall	3200Gbps	6.4Tbps	12.8Tbps 25.2Tbps	
0Tbps/1U		100Tbps/1U	Purple Brick Wall	400Tbps/1U	800Tbps/1
3O/CP	OSFP/OBO/CP	Purple Brick Wall		Micro-OSFP/OBO/CP	
<2km			<2km		<2k
5/Gbps	Purple Brick Wall	$0.25/Gbps		<$0.1/Gbps	
<$1/Gbps	Purple Brick Wall	<$0.5/Gbps		<$0.2/Gbps	<$0.
100m			1-100m		
25/Gbps	Purple Brick Wall	<$0.1/Gbps		<$0.05/Gbps	
<$0.5/Gbps		Purple Brick Wall	$0.25/Gbps	<$0.15/Gbps	
	Micro Ring resonator		Micro Ring resonator		

Sources: LWLG, iNEMI, AIM Photonics, Photon Delta

Hybrid PIC roadmap - datacom

2022 Roadmap | 2022 | 2024 | 2026 | 2028 | 2030……………..2040

Modules/TxRx / Data rate density / Form factor

800Gbps | 1600Gbps | Purple Brick Wall | *3200Gbps* | *6.4Tbps* | *12.8Tbps* | *25.2Tbps* | *50.4Tbps*

25 Tbps/1U | 50Tbps/1U | 100Tbps/1U | Purple Brick Wall | *400Tbps/1U* | *800Tbps/1U*

Q/OSFP | OSFP/OBO/CP | OSFP/OBO/CP | Purple Brick Wall | *Micro-OSFP/OBO/CP*

Typical link reach / Ind wish (@800Gbps) / *Industry plan*

<10km | <10km | <2km | <2km | <2km

<$1/Gbps | $0.5/Gbps | Purple Brick Wall | *$0.25/Gbps* | *<$0.1/Gbps*

$1-5/Gbps (<2km) | <$1/Gbps | Purple Brick Wall | *<$0.5/Gbps* | *<$0.2/Gbps* | *<$0.1/Gbps*

Typical link reach / Ind wish (@800Gbps) / *Industry plan*

10-100m | 5-100m | *1-100m*

<$0.5/Gbps | <$0.25/Gbps | Purple Brick Wall | *<$0.1/Gbps* | *<$0.05/Gbps*

$1-3/Gbps | <$1/Gbps | <$0.5/Gbps | Purple Brick Wall | *$0.25/Gbps* | *<$0.15/Gbps*

ACTIVE PLATFORM

Silicon Photonics — Modulator: TW carrier inj 25-35GHz (4-6V) | TW carrier inj 35GHz (3-6V) | Micro Ring resonator 50GHz (2-6V) | Purple Brick Wall | *Micro Ring resonator 70GHz (2-6V)*

Indium Phosphide — Laser/Modulator: PIC DD/Coherent DFB/DBR/SOA 30-40GHz (1-4V) | 1310/1550nm 35-50GHz (1-5V) | OEIC Tx/Rx DD/Coh with MSI 60GHz (2-8V) | Purple Brick Wall | *80GHz (3-10V)* | OEIC Tx/Rx DD/Coh with LSI

EO Polymer — Modulator: Slot waveguide 1310/1550nm 70GHz (<1V) | Integrated PIC slot W/G 1310/1550nm 100GHz (<0.5V) | 110GHz (<0.5V) | Purple Brick Wall | *150GHz (<1V)* | *170GHz*

Metal/plasmonic EO polymer — Modulator: Slot L/E PIC 1310/1550nm 100GHz (5-10V) | Coh/DD slot L/E PIC 1310/1550nm 150GHz (3-8V) | 200GHz (1-5V) | Purple Brick Wall | *300GHz (1-3V)* | *400GHz*

BTO — Modulator: Integrated with SiPh/CMOS 20-30GHz | Integrated PIC with CMOS 30-40GHz | Purple Brick Wall | *50GHz* | *70GHz*

TFLN — Modulator: Multi-channel array 50GHz (3-8V) | Integrated PIC with SiPh 70GHz (2-5V) | Integrated PIC with CMOS 90GHz (2-5V) | Purple Brick Wall | *100GHz*

PASSIVE PLATFORM

Silicon Photonics — WG/SSC/Mux/Coupler: Coherent/DD PIC w/Mux/SSC/PD/GC + LD source 30-40GHz | 50GHz | Purple Brick Wall | SSI OEIC IC+SiPh w/LD/MRR *70GHz* | MSI OEIC IC+SiPh + LD/MRR *80GHz*

Dielectric/Glass/Silica — WG/SSC/Mux/Coupler: PIC w/Mux/SSC/PD/GC + LD source 30-40GHz | 50GHz | SSI PIC with SiPh w/LD/Hybrid modulator 70GHz | Purple Brick Wall | *100GHz* | MSI PIC with SiPh w/LD/Hybrid modulator *120GHz*

InP — WG/SSC/Mux/Coupler: Coherent/DD PIC w/Mux/SSC/PD/GC + LD source 30-40GHz | 50GHz | 70GHz | SSI OEIC w/Hybrid modulator | Purple Brick Wall | *100GHz* | MSI OEIC w/Hybrid modulator *120GHz*

Polymer — WG/SSC/Mux/Coupler: Integrated PCB/Interposer w/Mux/SSC/PD/GC + LD source 30-40GHz | 50GHz | 70GHz | Purple Brick Wall | PCB/Interposer w/Mux/SSC/PD/GC w/LD/Hybrid modulator *80GHz* | *90GHz*

Normal Black Font = Reasonably expected based on current efforts	Purple Brick Wall = Technology cost barrier	*Slanted Red Font = Major industry effort required for commercialization*

Sources: LWLG, iNEMI, AIM Photonics, Photon Delta

Hybrid PIC roadmap - datacom

2022 Roadmap	2022	2024	2026	2028	2030……………..2040
Modules/TxRx	800Gbps	1600Gbps / Purple Brick Wall	*3200Gbps 6.4Tbps*	*12.8Tbps 25.2Tbps*	*50.4Tbps*
Data rate density	25 Tbps/1U	50Tbps/1U	100Tbps/1U / Purple Brick Wall	*400Tbps/1U*	*800Tbps/1U*
Form factor	Q/OSFP	OSFP/OBO/CP	OSFP/OBO/CP / Purple Brick Wall	*Micro-OSFP/OBO/CP*	
Typical link reach	<10km	<10km	<2km	<2km	*<2km*
Ind wish (@800Gbps)	<$1/Gbps	$0.5/Gbps	Purple Brick Wall / *$0.25/Gbps*		*<$0.1/Gbps*
Industry plan	$1-5/Gbps (<2km)	<$1/Gbps	Purple Brick Wall / *<$0.5/Gbps*	*<$0.2/Gbps*	*<$0.1/Gbps*
Typical link reach	10-100m	5-100m		*1-100m*	
Ind wish (@800Gbps)	<$0.5/Gbps	<$0.25/Gbps	Purple Brick Wall / *<$0.1/Gbps*	*<$0.05/Gbps*	
Industry plan	$1-3/Gbps	<$1/Gbps / <$0.5/Gbps	Purple Brick Wall	*$0.25/Gbps* / *<$0.15/Gbps*	

ACTIVE PLATFORM

	2022	2024	2026	2028	2030……………..2040
Silicon Photonics Modulator	TW carrier inj 25-35GHz (4-6V)	TW carrier inj 35GHz (3-6V)	Micro Ring resonator 50GHz (2-6V) / Purple Brick Wall	*Micro Ring resonator 70GHz (2-6V)*	
Indium Phosphide Laser/Modulator	PIC DD/Coherent DFB/DBR/SOA 30-40GHz (1-4V)	1310/1550nm 35-50GHz (1-5V)	OEIC Tx/Rx DD/Coh with MSI 60GHz (2-8V) / Purple Brick Wall	*80GHz (3-10V)*	OEIC Tx/Rx DD/Coh with LSI
EO Polymer Modulator	Slot waveguide 1310/1550nm 70GHz (<1V)	Integrated PIC slot W/G 1310/1550nm 100GHz (<0.5V)	110GHz (<0.5V)	Purple Brick Wall	*150GHz (<1V)* *170GHz*
Metal/plasmonic EO polymer Modulator	Slot L/E PIC 1310/1550nm 100GHz (5-10V)	150GHz (3-8V)	Coh/DD slot L/E PIC 1310/1550nm 200GHz (1-5V)	Purple Brick Wall	*300GHz (1-3V)* *400GHz*
BTO Modulator	Integrated with SiPh/CMOS 20-30GHz	Integrated PIC with CMOS 30-40GHz	Purple Brick Wall / *50GHz*	*70GHz*	
TFLN Modulator	Multi-channel array 50GHz (3-8V)	Integrated PIC with SiPh 70GHz (2-5V)	Integrated PIC with CMOS 90GHz (2-5V) / Purple Brick Wall		*100GHz*

PASSIVE PLATFORM

	2022	2024	2026	2028	2030……………..2040
Silicon Photonics WG/SSC/Mux/Coupler	Coherent/DD PIC w/Mux/SSC/PD/GC + LD source 30-40GHz	50GHz	Purple Brick Wall / SSI OEIC IC+SiPh w/LD/MRR *70GHz*	MSI OEIC IC+SiPh + LD/MRR *80GHz*	
Dielectric/Glass/Silica WG/SSC/Mux/Coupler	PIC w/Mux/SSC/PD/GC + LD source 30-40GHz		SSI PIC with SiPh w/LD/Hybrid modulator	MSI PIC with SiPh w/LD/Hybrid modulator	*120GHz*
InP WG/SSC/Mux/Coupler	Coherent/DD PIC w/Mux/SSC/PD/GC + LD source 30-40GHz	50GHz	70GHz / SSI OEIC w/Hybrid modulator / Purple Brick Wall	*100GHz* / MSI OEIC w/Hybrid modulator	*120GHz*
Polymer WG/SSC/Mux/Coupler	Integrated PCB/Interposer w/Mux/SSC/PD/GC + LD source 30-40GHz	50GHz	70GHz / Purple Brick Wall / PCB/Interposer w/Mux/SSC/PD/GC w/LD/Hybrid modulator	*80GHz*	*90GHz*

Enlarged next slide

Normal Black Font = Reasonably expected based on current efforts	**Purple Brick Wall** = Technology cost barrier	*Slanted Red Font* = Major industry effort required for commercialization

Sources: LWLG, iNEMI, AIM Photonics, Photon Delta

Hybrid PIC roadmap - datacom

2022 Roadmap	2022	2024	2026	2028	2030……………..2040

Modules/TxRx, Data rate density, Form factor

- 800Gbps — 1600Gbps — Purple Brick Wall — *3200Gbps* — *6.4Tbps* — *12.8Tbps* — *25.2Tbps* — *50.4Tbps*
- 25 Tbps/1U — 50Tbps/1U — 100Tbps/1U — Purple Brick Wall — *400Tbps/1U* — *800Tbps/1U*
- Q/OSFP — OSFP/OBO/CP — OSFP/OBO/CP — Purple Brick Wall — *Micro-OSFP/OBO/CP*

Typical link reach, Ind wish (@800Gbps)

- <10km — <10km — <2km — <2km — *<2km*
- <$1/Gbps — $0.5/Gbps — Purple Brick Wall — *$0.25/Gbps* — *<$0.1/Gbps*

ACTIVE PLATFORM

- *Silicon Photonics Modulator*: TW carrier inj 25-35GHz (4-6V) — TW carrier inj 35GHz (3-6V) — Micro Ring resonator 50GHz (2-6V) — Purple Brick Wall — *Micro Ring resonator 70GHz (2-6V)*
- *Indium Phosphide Laser/Modulator*: PIC DD/Coherent DFB/DBR/SOA 1310/1550nm 30-40GHz (1-4V) — 35-50GHz (1-5V) — OEIC Tx/Rx DD/Coh with MSI 60GHz (2-8V) — Purple Brick Wall — *80GHz (3-10V)* — OEIC Tx/Rx DD/Coh with LSI
- *EO Polymer Modulator*: Slot waveguide 1310/1550nm 70GHz (<1V) — Integrated PIC slot W/G 1310/1550nm 100GHz (<0.5V) — 110GHz (<0.5V) — Purple Brick Wall — *150GHz (<1V)*
- *Metal/plasmonic EO polymer Modulator*: Slot L/E PIC 1310/1550nm 100GHz (5-10V) — Coh/DD slot L/E PIC 1310/1550nm 150GHz (3-8V) — 200GHz (1-5V) — Purple Brick Wall — *300GHz (1-3V)*
- *BTO Modulator*: Integrated with SiPh/CMOS 20-30GHz — Integrated PIC with CMOS 30-40GHz — Purple Brick Wall — *50GHz* — *70GHz*
- *TFLN Modulator*: Multi-channel array 50GHz (3-8V) — Integrated PIC with SiPh 70GHz (2-5V) — Integrated PIC with CMOS 90GHz (2-5V) — Purple Brick Wall — *100GHz*

PASSIVE PLATFORM

- *Silicon Photonics WG/SSC/Mux/Coupler*: Coherent/DD PIC w/Mux/SSC/PD/GC + LD source 30-40GHz — 50GHz — Purple Brick Wall — SSI OEIC IC+SiPh w/LD/MRR *70GHz* — MSI OEIC IC+SiPh + LD/MRR *80GHz*
- *Dielectric/Glass/Silica WG/SSC/Mux/Coupler*: PIC w/Mux/SSC/PD/GC + LD source 30-40GHz — 50GHz — SSI PIC with SiPh w/LD/Hybrid modulator 70GHz — Purple Brick Wall — *100GHz* — MSI PIC with SiPh w/LD/Hybrid modulator *120GHz*
- *InP WG/SSC/Mux/Coupler*: Coherent/DD PIC w/Mux/SSC/PD/GC + LD source 30-40GHz — 50GHz — 70GHz — SSI OEIC w/Hybrid modulator — Purple Brick Wall — *100GHz* — MSI OEIC w/Hybrid modulator *120GHz*
- *Polymer WG/SSC/Mux/Coupler*: Integrated PCB/Interposer w/Mux/SSC/PD/GC + LD source 30-40GHz — 50GHz — 70GHz — Purple Brick Wall — PCB/Interposer w/Mux/SSC/PD/GC w/LD/Hybrid modulator *80GHz* — *90GHz*

Normal Black Font = Reasonably expected based on current efforts	Purple Brick Wall = Technology cost barrier	*Slanted Red Font = Major industry effort required for commercialization*

Sources: LWLG, iNEMI, AIM Photonics, Photon Delta

Draft Roadmap 2022 (NEW)

Warning - Eye-chart!

Don't try and read it – zoom soon

(can be found at www.lightwavelogic.com)

Hybrid PIC roadmap - datacom

2022 Roadmap	2022	2024	2026	2028	2030…………….2040

Modules/TxRx / Data rate density / Form factor

800Gbps · 1600Gbps · Purple Brick Wall · *3200Gbps* · *6.4Tbps* · *12.8Tbps* · *25.2Tbps* · *50.4Tbps*
25 Tbps/1U · 50Tbps/1U · 100Tbps/1U · Purple Brick Wall · *400Tbps/1U* · *800Tbps/1U*
Q/OSFP · OSFP/OBO/CP · OSFP/OBO/CP · Purple Brick Wall · *Micro-OSFP/OBO/CP*

Typical link reach / Ind wish (@800Gbps) / *Industry plan*

<10km · <10km · <2km · <2km · *<2km*
<$1/Gbps · $0.5/Gbps · Purple Brick Wall · *$0.25/Gbps* · *<$0.1/Gbps*
$1-5/Gbps (<2km) · <$1/Gbps · Purple Brick Wall · *<$0.5/Gbps* · *<$0.2/Gbps* · *<$0.1/Gbps*

Typical link reach / Ind wish (@800Gbps) / *Industry plan*

10-100m · 5-100m · *1-100m*
<$0.5/Gbps · <$0.25/Gbps · Purple Brick Wall · *<$0.1/Gbps* · *<$0.05/Gbps*
$1-3/Gbps · <$1/Gbps · <$0.5/Gbps · Purple Brick Wall · *$0.25/Gbps* · *<$0.15/Gbps*

ACTIVE PLATFORM

Silicon Photonics — Modulator
TW carrier inj · TW carrier inj · Micro Ring resonator · Micro Ring resonator
25-35GHz (4-6V) · 35GHz (3-6V) · 50GHz (2-6V) · Purple Brick Wall · *70GHz (2-6V)*

Indium Phosphide — Laser/Modulator
PIC DD/Coherent DFB/DBR/SOA 1310/1550nm · OEIC Tx/Rx DD/Coh with MSI · OEIC Tx/Rx DD/Coh with LSI
30-40GHz (1-4V) · 35-50GHz (1-5V) · 60GHz (2-8V) · Purple Brick Wall · *80GHz (3-10V)*

EO Polymer — Modulator
Slot waveguide 1310/1550nm · Integrated PIC slot W/G 1310/1550nm
70GHz (<1V) · 100GHz (<0.5V) · 110GHz (<0.5) · Purple Brick Wall · *150GHz (<1V)* · *170GHz*

Metal/plasmonic EO polymer — Modulator
Slot L/E PIC 1310/1550nm · Coh/DD slot L/E PIC 1310/1550nm
100GHz (5-10V) · 150GHz (3-8V) · 200GHz (1-5V) · Purple Brick Wall · *300GHz (1-3V)* · *400GHz*

BTO — Modulator
Integrated with SiPh/CMOS · Integrated PIC with CMOS
20-30GHz · 30-40GHz · Purple Brick Wall · *50GHz* · *70GHz*

TFLN — Modulator
Multi-channel array · Integrated PIC with SiPh · Integrated PIC with CMOS
50GHz (3-8V) · 70GHz (2-5V) · 90GHz (2-5V) · Purple Brick Wall · *100GHz*

PASSIVE PLATFORM

Silicon Photonics — WG/SSC/Mux/Coupler
Coherent/DD PIC w/Mux/SSC/PD/GC + LD source · SSI OEIC IC+SiPh w/LD/MRR · MSI OEIC IC+SiPh + LD/MRR
30-40GHz · 50GHz · Purple Brick Wall · *70GHz* · *80GHz*

Dielectric/Glass/Silica — WG/SSC/Mux/Coupler
PIC w/Mux/SSC/PD/GC + LD source · SSI PIC with SiPh w/LD/Hybrid modulator · MSI PIC with SiPh w/LD/Hybrid modulator
30-40GHz · 50GHz · 70GHz · Purple Brick Wall · *100GHz* · *120GHz*

InP — WG/SSC/Mux/Coupler
Coherent/DD PIC w/Mux/SSC/PD/GC + LD source · SSI OEIC w/Hybrid modulator · MSI OEIC w/Hybrid modulator
30-40GHz · 50GHz · 70GHz · Purple Brick Wall · *100GHz* · *120GHz*

Polymer — WG/SSC/Mux/Coupler
Integrated PCB/Interposer w/Mux/SSC/PD/GC + LD source · PCB/Interposer w/Mux/SSC/PD/GC w/LD/Hybrid modulator
30-40GHz · 50GHz · 70GHz · Purple Brick Wall · *80GHz* · *90GHz*

Normal Black Font = Reasonably expected based on current efforts	**Purple Brick Wall** = Technology cost barrier	*Slanted Red Font* = Major industry effort required for commercialization

Sources: LWLG, iNEMI, AIM Photonics, Photon Delta

Hybrid PIC roadmap - datacom

2022 Roadmap | 2022 | 2024 | 2026 | 2028 | 2030……………..2040

Modules/TxRx / Data rate density / Form factor
800Gbps | 1600Gbps | Purple Brick Wall | *3200Gbps* | *6.4Tbps* | *12.8Tbps* | *25.2Tbps* | *50.4Tbps*
25 Tbps/1U | 50Tbps/1U | 100Tbps/1U | Purple Brick Wall | *400Tbps/1U* | *800Tbps/1U*
Q/OSFP | OSFP/OBO/CP | OSFP/OBO/CP | Purple Brick Wall | *Micro-OSFP/OBO/CP*

Typical link reach / Ind wish (@800Gbps) / *Industry plan*
<10km | <10km | <2km | <2km | *<2km*
<$1/Gbps | $0.5/Gbps | Purple Brick Wall | *$0.25/Gbps* | *<$0.1/Gbps*
$1-5/Gbps (<2km) | <$1/Gbps | Purple Brick Wall | *<$0.5/Gbps* | *<$0.2/Gbps* | *<$0.1/Gbps*

Typical link reach / Ind wish (@800Gbps) / *Industry plan*
10-100m | 5-100m | *1-100m*
<$0.5/Gbps | <$0.25/Gbps | Purple Brick Wall | *<$0.1/Gbps* | *<$0.05/Gbps*
$1-3/Gbps | <$1/Gbps | <$0.5/Gbps | Purple Brick Wall | *$0.25/Gbps* | *<$0.15/Gbps*

ACTIVE PLATFORM
Silicon Photonics Modulator
TW carrier inj 25-35GHz (4-6V) | TW carrier inj 35GHz (3-6V) | Micro Ring resonator 50GHz (2-6V) | Purple Brick Wall | *Micro Ring resonator 70GHz (2-6V)*
Indium Phosphide Laser/Modulator
PIC DD/Coherent DFB/DBR/SOA 1310/1550nm 30-40GHz (1-4V) | 35-50GHz (1-5V) | OEIC Tx/Rx DD/Coh with MSI 60GHz (2-8V) | Purple Brick Wall | *80GHz (3-10V)* | OEIC Tx/Rx DD/C
EO Polymer Modulator
Slot waveguide 1310/1550nm 70GHz (<1V) | Integrated PIC slot W/G 1310/1550nm 100GHz (<0.5V) | 110GHz (<0.5) | Purple Brick Wall | *150G*
Metal/plasmonic EO polymer Modulator
Slot L/E PIC 1310/1550nm 100GHz (5-10V) | 150GHz (3-8V) | Coh/DD slot L/E PIC 1310/1550nm 200GHz (1-5V) | Purple Brick Wall | *30*
BTO Modulator
Integrated with SiPh/CMOS 20-30GHz | Integrated PIC with CMOS 30-40GHz | Purple Brick Wall | *50GHz* | *70GHz*
TFLN Modulator
Multi-channel array 50GHz (3-8V) | Integrated PIC with SiPh 70GHz (2-5V) | Integrated PIC with CMOS 90GHz (2-5V) | Purple Brick Wall | *100GHz*

PASSIVE PLATFORM
Silicon Photonics WG/SSC/Mux/Coupler
Coherent/DD PIC w/Mux/SSC/PD/GC + LD source 30-40GHz | 50GHz | Purple Brick Wall | SSI OEIC IC+SiPh w/LD/MRR *70GHz* | MSI OEIC IC+SiPh *80GHz*
Dielectric/Glass/Silica WG/SSC/Mux/Coupler
PIC w/Mux/SSC/PD/GC + LD source 30-40GHz | 50GHz | SSI PIC with SiPh w/LD/Hybrid modulator 70GHz | Purple Brick Wall | *100GHz* | MSI PIC with SiPh w/LD/Hybrid modulator *120GHz*
InP WG/SSC/Mux/Coupler
Coherent/DD PIC w/Mux/SSC/PD/GC + LD source 30-40GHz | 50GHz | 70GHz | SSI OEIC w/Hybrid modulator | Purple Brick Wall | *100GHz* | MSI OEIC w/Hybrid modulator *120GHz*
Polymer WG/SSC/Mux/Coupler
Integrated PCB/Interposer w/Mux/SSC/PD/GC + LD source 30-40GHz | 50GHz | 70GHz | Purple Brick Wall | PCB/Interposer w/Mux/SSC/PD/GC w/LD/Hybrid modulator *80GHz* | *90GHz*

Purple region shows trends of the 'purple brick wall' □ areas that need to be addressed seriously

Normal Black Font = Reasonably expected based on current efforts	**Purple Brick Wall** = Technology cost barrier	*Slanted Red Font* = Major industry effort required for commercialization

Sources: LWLG, iNEMI, AIM Photonics, Photon Delta

Observations…
For debate…

Observations and *controversial topics…*

2022 Roadmap	2022	2024	2026	2028	2030……………..2040
Modules/TxRx Data rate density Form factor	800Gbps 25 Tbps/1U Q/OSFP	1600Gbps 50Tbps/1U OSFP/OBO/CP	Purple Brick Wall *3200Gbps* 100Tbps/1U Purple Brick Wall OSFP/OBO/CP Purple Brick Wall	*6.4Tbps 12.8Tbps* *400Tbp* *Micro*	*Tbps /1U 50.4Tbps*
Typical link reach Ind wish (@800Gbps) *Industry plan*	<10km <$1/Gbps $1-5/Gbps (<2km)	<10km $0.5/Gbps <$1/Gbps	<2km Purple Brick Wall *$0.25/Gbps* Purple Brick Wall *<$0.5/Gbps*	<2km *<$0.2/G*	<2km *1/Gbps* *<$0.1/Gbps*
Typical link reach Ind wish (@800Gbps) *Industry plan*	10-100m <$0.5/Gbps $1-3/Gbps	5-100m <$0.25/Gbps <$1/Gbps <$0.5/Gbps	Purple Brick Wall *<$0.1/Gbps* Purple Brick Wall	*$0.25/Gbps* *1-100m*	

ACTIVE PLATFORM

	2022	2024	2026	2028	2030……………..2040
Silicon Photonics Modulator	TW carrier inj 25-35GHz (4-6V)	TW carrier inj 35GHz (3-6V)	Micro Ring resonator 50GHz (2-6V) Purple Brick Wall	*Micro Ring resonator 70GHz (2-6V)*	
Indium Phosphide Laser/Modulator	PIC DD/Coherent DFB/DBR/SOA 30-40GHz (1-4V)	1310/1550nm 35-50GHz (1-5V)	OEIC Tx/Rx DD/Coh with MSI 60GHz (2-8V) Purple Brick Wall	*80GHz (3-10V)*	OEIC Tx/Rx DD/Coh with LSI
EO Polymer Modulator	slot waveguide 1310/1550nm 70GHz (<1V)	In… 10…	…ed PIC slot W/G 1310/1550nm 110GHz (<0.5)	Purple Brick Wall	*150GHz (<…* *170GHz*
Metal/plasmonic EO polymer Modulator	slot L/E PIC 1310/1550nm 100GHz (5-10V)		…D slot L/E PIC 1310/1550nm	200GHz (1-5V) Purple Brick Wall	*300…* *…Hz*
BTO Modulator	ntegrated with SiPh/CMOS 20-30GHz	…0G…	…rated PIC with CMOS Purple Brick Wall *50GHz*	*70GHz*	
TFLN Modulator			…ated PIC with SiPh …z (2-5V)	Integrated PIC with CMOS 90GHz (2-5V) Purple Brick Wall	*100GHz*

…ATFORM

	2022	2024	2026	2028	2030……………..2040
Si… …ux/Coupler		LD source …GHz	Purple Brick Wall	SSI OEIC IC+SiPh w/LD/MRR *70GHz*	MSI OEIC IC+SiPh + LD/MRR *80GHz*
…ca …SC/Mux/Coupler		…z	SSI PIC with SiPh w/LD/Hybrid modulator 70GHz Purple Brick Wall	*100GHz*	MSI PIC with SiPh w/LD/Hybr… *120GHz*
…/SSC/Mux/Coupler		LD source	70GHz	SSI OEIC w/Hybrid modulator Purple Brick Wall *100GHz*	MSI OEIC w/Hybrid modulat… *120GHz*
…upler		PD/GC + LD source 70GHz	Purple Brick Wall *80GHz*	PCB/Interposer w/Mux/SSC/PD/GC w/LD/Hybrid modulator	*90GHz*

…al Black F… …sonably e… …s | **Purple Brick Wall** …chnology cost barrier | *Slanted Red Font = Major industry effort required for commercialization*

Challenge for Tbps transceivers – is this possible?

Challenge for cost per Gbps (@800Gbps) – will we achieve the cost metrics?

Hybrid technologies with natural speed/low power – when will they be implemented?

Trend for higher integration with a hybrid PIC – are we going to see electronics, and higher integration levels with mix/match technologies?

Hybrid modulators – will they be key for PICs this decade?

Sources: LWLG, iNEMI, AIM Photonics, Photon Delta

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lightwavelogic.com

Thank you!

Back up

Draft PIC package roadmap

2022 Roadmap (PIC Packaging)

	2021	2022	2024	2026	2028	2030

Modules/TxRx – Data rate density – Form factor

400Gbps — 800Gbps — 1600Gbps — *3200Gbps* — *6400Gbps*
25 Tbps/1U — 100Tbps/1U — 400Tbps/1U — *1600Tbps/1U*
Q/OSFP — OSFP/OBO/CP — *OBO/CP* — *Co-Pkg/CoB* — *Micro-Co-Pkg/CoB*

Typical link reach – Ind wish (@800Gbps) – *Industry plan*

<10km — <10km — <2km — <2km — *<2km*
$2/Gbps — $1/Gbps — *$0.5/Gbps* — *<$0.2/Gbps*
>$5/Gbps (<2km) — <$2/Gbps — *$0.5/Gbps* — *$0.2/Gbps*

Typical link reach – Ind wish (@800Gbps) – *Industry plan*

10-100m — 5-50m — *1-25m*
<$1/Gbps — <$0.5/Gbps — *<$0.25/Gbps* — *<$0.05/Gbps*
$1/Gbps — *$0.25/Gbps* — *<$0.15/Gbps*

Gold Box

Butterfly — micro-butterfly — *nano-butterfly*
50GHz. — 100GHz — 150GHz — *200GHz*
Form factor: PIC chips <10 functions — 10-50 functions — *100-200 functions* — *500 functions*

Surface mount

SOIC (<50 lead) — micro-SOIC (<50 lead — *(100+ lead)*
25GHz. — 50GHz — 70GHz (100Gbps NRZ) — *100GHz (130Gbps NRZ)*
Connectorized SM/MM fiber — Fiber ribbons 1x12/24 — 2D fiber ribbons 2x24/48 — *2D fiber ribbons >500 fibers*
Flip-chip bumping to pcb <100 bumps — <250 bumps — <1000 bumps — *<10,000 bumps*
Thermal passive heat management — advanced thermal designs

Chip-on-board & wafer-scale

Flip-chip bump (100) — 1000 devices — 10000 devices — *100,000 devices*
Interconnect bandwidth 25GHz. — 50GHz — 70GHz — 100GHz — *200GHz*
Wafer format 150mm — 200mm — 300mm — *450mm*
Fiber to PIC packaging (grating/edge) — micro-optics to PIC packaging (grating/edge) — *terposer to PIC packaging (edge/evanescent)*
2D Integration — 2.5D integration — *3D integration*

Co-pkg (layer 1 – CoC)

2 chips — 10 chips — 30 chips — *50 chips*
25GHz. — 50GHz — 70GHz — *150GHz*
2D Integration (electronic IC on PIC) — 2.5D integration (electronic IC and PIC on carrier — *PIC on interposer (Optical)*
Active cooling (standard TEC) — Customized TEC/controller — *micro-TEC pkg with PIC* — *TEC integrated directly PIC*
Passive cooling (std heat spreaders) — *Graphene based materials.* — *Integrated with PIC Pkg.* — *Integrated with PIC*

Co-pkg (layer 2 - Comp)

10 devices — 100 devices — *1000 devices*
25GHz. — 50GHz — 70GHz
Single die — twin die — multiple die 2D — *multiple die 3D/fan out interconnect* — *multiple die 3D/double sided*
Optical platform 150mm — Optical platform 200mm — *optical platform 300mm*
Electronic and photonic PIC 2D package — electronic and photonics PIC 2.5D package — *C 3D package platform*

Normal Black Font = Reasonably expected based on current efforts	**Purple Brick Wall** = Technology cost barrier	*Slanted Red Font* = Major industry effort required for commercialization

CoC = Chip-on-Carrier

A PIC Packaging roadmap…trends towards chip scale packaging/Testing-Assembly-Packaging (CSP-TAP)

Source: Lightwave Logic, EPIC

Draft PIC package roadmap

2022 Roadmap (PIC Packaging)	2021	2022	2024	2026	2028	2030
Modules/TxRx Data rate density Form factor	400Gbps 25 Tbps/1U Q/OSFP	800Gbps OSFP/OBO/CP	1600Gbps 100Tbps/1U *OBO/CP*	*3200Gbps* 400Tbps/1U *Co-Pkg/CoB*	*1600Tbps/1U* *Micro-Co-Pkg/CoB*	*6400Gbps*
Typical link reach Ind wish (@800Gbps) *Industry plan*	<10km $2/Gbps >$5/Gbps (<2km)	<10km $1/Gbps	<2km <$2/Gbps *$0.5/Gbps*	<2km *$0.5/Gbps*	*<$0.2/Gbps* <2km	*$0.2/Gbps*
Typical link reach Ind wish (@800Gbps) *Industry plan*	10-100m <$1/Gbps	$1/Gbps 5-50m <$0.5/Gbps	*<$0.25/Gbps*	*1-25m* *$0.25/Gbps*	*<$0.05/Gbps*	*<$0.15/Gbps*
Gold Box	Butterfly 50GHz. Form factor: PIC chips <10 functions	micro-butterfly 100GHz	150GHz 10-50 functions	*nano-butterfly* *100-200 functions*	*200GHz*	*500 functions*
Surface mount	SOIC (<50 lead) 25GHz. 50GHz Connectorized SM/MM fiber Flip-chip bumping to pcb <100 bumps Thermal passive heat management	Fiber ribbons 1x12/24	micro-SOIC (<50 lead 70GHz (100Gbps NRZ) <250 bumps <1000 bumps advanced thermal designs	2D fiber ribbons 2x24/48 *(100+ lead)*	*100GHz (130Gbps NRZ)* *2D fiber ribbo* *<10,000 bum*	
Chip-on-board & wafer-scale	Flip-chip bump (100) Interconnect bandwidth 25GHz. Wafer format 150mm Fiber to PIC packaging (grating/edge) 2D Integration	1000 devices 50GHz 200mm micro-optics to PIC packaging (grating/edge) 2.5D integration	10000 devices 70GHz 300mm	100GHz *3D integration* *terposer to PIC packaging (edge/evanescent)*	*100,000 devices* *450mm*	*200GHz*
Co-pkg (layer 1 – CoC)	2 chips 25GHz. 10 chips 50GHz 2D Integration (electronic IC on PIC) Active cooling (standard TEC) Passive cooling (std heat spreaders)	30 chips 2.5D integration (electronic IC and PIC on carrier Customized TEC/controller	70GHz *Graphene based materials.*	*150GHz* *micro-TEC pkg with PIC* *Integrated with PIC Pkg.*	*50 chips* *PIC on interposer (Optical)* *TEC integrated directly PIC*	*Integrated with PIC*
Co-pkg (layer 2 - Comp)	10 devices 25GHz. 50GHz Single die twin die Optical platform 150mm Electronic and photonic PIC 2D package	100 devices multiple die 2D Optical platform 200mm	70GHz electronic and photonics PIC 2.5D package	*1000 devices* *multiple die 3D/fan out interconnect* *optical platform 300mm*	*multiple die 3D/double sided* *C 3D package platform*	

Normal Black Font = Reasonably expected based on current efforts	**Purple Brick Wall** **= Technology cost barrier**	*Slanted Red Font = Major industry effort required for commercialization*

As per the silicon electronics industry → Chip scale packaging (CSP-TAP)

CoC = Chip-on-Carrier

A PIC Packaging roadmap…trends towards chip scale packaging/Testing-Assembly-Packaging (CSP-TAP)

Source: Lightwave Logic, EPIC