



LIGHTWAVELOGIC™

Faster by Design

Integrated photonics roadmaps: enabling high performance packaging

Michael Leiby, CEO, Lightwave Logic Inc.

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This grey bar is the takeaway summary from each slide...



2016 Roadmap	2017	2018	2020	2022	2024	2026
Modules/TxRx Data rate density Form factor	100Gbps 10 Tbps/1U QSFP		400Gbps 25Tbps/1U DSFP	Purple Brick Wall 100Tbps/1U FP+ (new)	1000Gbps 400Tbps/1U Micro-SFP	
Typical link reach Ind wish (@400Gbps) Industry plan	<10km \$5/Gbps >\$10/Gbps (<2km)	<10km	<2km \$1/Gbps	2km \$1/Gbps	<2km <\$0.5/Gbps	<2km \$0.5/Gbps
Typical link reach Ind wish (@400Gbps) Industry plan	10-100m <\$1/Gbps	5-50m \$1/Gbps	<\$0.5/Gbps	1-25m \$0.25/Gbps	<\$0.05/Gbps	<\$0.15/Gbps
InP Monolithic	100 devices 25Gbps PIC WDM Tx & Rx NRZ/PAM4 & NRZ/PAM4-8 3" Wafer/fab	50Gbps OEIC Int driver/TIA 50Gbps	1000 devices 100Gbps NRZ/PAM4-16 4 & 6" Wafer/fab	Purple Brick Wall 1000 devices OEIC Int driver/TIA 100Gbps (serial) Purple Brick Wall	400Gbps 100Gbps (serial) Coherent client-side	100,000 devices OEIC ASIC 50Gbps
SiP & InP/SiGe hybrid	10 devices 25Gbps PIC WDM Tx & Rx NRZ/PAM4 & NRZ/PAM4-8 6" Wafer/fab	100 devices 50Gbps OEIC Int driver/TIA 50Gbps	100Gbps OEIC Int driver/TIA 100Gbps (serial) NRZ/PAM4-16 8 & 12" Wafer/fab	Purple Brick Wall 1000 devices 100Gbps (serial) Purple Brick Wall	400Gbps Coherent client-side	10,000 devices OEIC ASIC 50Gbps
Polymer Photonics	25Gbps PIC WDM/MZ Mod Tx & Rx NRZ/PAM4 & NRZ/PAM4-8 3-4" Wafer/fab	10 devices 50Gbps (Laser-Mod)	100 devices 100Gbps (laser-Mod) OEIC Int driver/TIA (SiP/InP) 50Gbps NRZ/PAM4-16 4" Wafer/fab	Purple Brick Wall 1000 devices OEIC Int driver/TIA (SiP/InP) 100Gbps (serial) Purple Brick Wall	1000 devices 400Gbps Coherent client-side	10,000 devices OEIC ASIC 50Gbps
Dielectric Photonics	100 devices 25Gbps PIC Tx & Rx NRZ/PAM4 & NRZ/PAM4-8 6" Wafer/fab	50Gbps	1000 devices 100Gbps OEIC Int driver/TIA 50Gbps NRZ/PAM4-16 8" Wafer/fab	10,000 devices 400Gbps Purple Brick Wall	100,000 devices OEIC Int driver/TIA 100Gbps (serial) Coherent client-side	15" Wafer/fab
GaAs (VCSEL)	10 devices 25Gbps VCSEL PIC 25Gbps NRZ/PAM4 & NRZ/PAM4-8 3-4" Wafer/fab	100 devices 50Gbps VCSEL PIC 50Gbps	Purple Brick Wall 1000 devices 100Gbps (VCSEL-Mod) NRZ/PAM4-16 Purple Brick Wall	Purple Brick Wall 10,000 devices VCSEL PIC 100Gbps (serial) Purple Brick Wall	10,000 devices 400Gbps (VCSEL-Mod) Coherent client-side	

TxRx 400bps by Design

<\$5/Gbps

<\$1/Gbps

50Gbps PIC

50Gbps PIC

100Gbps mod

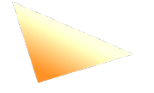
50Gbps PIC

100+ devices

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

Was the prediction accurate 4 years on?



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	Purple Brick Wall 100Tbps/1U <i>OBO/CP</i>	Purple Brick Wall 1600Gbps Purple Brick Wall 400Tbps/1U <i>Co-Pkg/CoB</i>	<i>3200Gbps</i> <i>1600Tbps/1U</i> <i>Micro-Co-Pkg/CoB</i>	
Typical link reach Ind wish (@400Gbps) <i>Industry plan</i>	<10km \$2/Gbps >\$5/Gbps (<2km)	<10km \$1/Gbps <\$2/Gbps	Purple Brick Wall	<i>\$0.5/Gbps</i> <i>\$0.5/Gbps</i>	<i><\$0.2/Gbps</i>	<2km \$0.2/Gbps
Typical link reach Ind wish (@400Gbps) <i>Industry plan</i>	10-100m <\$1/Gbps	5-50m <\$0.5/Gbps	Purple Brick Wall	<i><\$0.25/Gbps</i> <i>\$0.25/Gbps</i>	<i><\$0.05/Gbps</i> <i>\$0.25/Gbps</i>	<i><\$0.15/Gbps</i>
<i>InP Monolithic</i>	100 devices 25GHz, 50GHz PIC WDM Tx & Rx (30GHz) NRZ/PAM4 3" Wafer/fab	1000 devices 70GHz OEIC Int driver/TIA NRZ/PAM4-8 4" Wafer/fab	Purple Brick Wall 1000 devices 90GHz OEIC Int driver/TIA NRZ/PAM4-16 4 & 6" Wafer/fab	Purple Brick Wall 10000 devices 90GHz OEIC Int driver/TIA Coherent client-side 4 & 6" Wafer/fab	Purple Brick Wall 100GHz 400Gbps (70GHz) OEIC ASIC 50Gbps (50GHz) 8" Wafer/fab?	100,000 devices
<i>SiP & InP/SiGe hybrid</i>	10 devices 25GHz, 50GHz PIC WDM Tx & Rx (30GHz) NRZ/PAM4 & NRZ/PAM4-8 6" Wafer/fab	100 devices 70GHz OEIC Int driver/TIA NRZ/PAM4-16 8" Wafer/fab	1000 devices 70GHz (100Gbps) 50Gbps (50GHz) Coherent client-side 8 & 12" Wafer/fab	10000 devices 70GHz (400Gbps) OEIC Int driver/TIA Coherent SP-less 8 & 12" Wafer/fab	10,000 devices OEIC Int driver/TIA 100Gbps (serial) 15" Wafer/fab?	
<i>Polymer Photonics</i>	10 devices 25GHz, 50GHz (Laser-Mod) PIC WDM/MZ Mod Tx & Rx NRZ/PAM4 & NRZ/PAM4-8 3-4" Wafer/fab	1000 devices 70GHz (laser-Mod) OEIC Int driver/TIA (SiP/InP) NRZ/PAM4-16 4" Wafer/fab	10000 devices 100GHz (150Gbps serial) 50GHz OEIC Int driver/TIA Coherent client-side 4 & 6" Wafer/fab	10000 devices 100GHz (150Gbps serial) OEIC Int driver/TIA (SiP/InP) Coherent client-side 8" Wafer/fab	1000 devices 70GHz (serial) OEIC ASIC 70GHz 15" Wafer/fab	10,000 devices
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<i>GaAs (VCSEL)</i>	100 devices 25GHz, 50GHz VCSEL PIC 25GHz NRZ/PAM4 & NRZ/PAM4-8 6" Wafer/fab	1000 devices 50GHz VCSEL PIC 50GHz NRZ/PAM4-16 8" Wafer/fab	10000 devices 70GHz OEIC Int driver/TIA Coherent client-side 8" Wafer/fab	100,000 devices 70GHz (VCSEL-Mod) VCSEL PIC 70GHz (100Gbps) Coherent client-side	100,000 devices	

1600Gbps+
modules

<\$1/Gbps

90GHz devices?

70GHz devices?

100GHz devices

1000 devices
per chip

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Source: Lightwave Logic

Integrated photonics roadmap prediction for 2023: Packaging must enable 'fast and energy efficient'...

2020 Roadmap

2019 2020 2022 2024 2026 2028

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	100Tbps/1U OBO/CP	400Tbps/1U Co-Pkg/CoB	1600Gbps Micro-Co-Pkg/CoB	3200Gbps
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SiP & InP/SiGe hybrid	10 devices 25GHz, 50GHz PIC WDM Tx & Rx (30GHz) NRZ/PAM4 & NRZ/PAM4-8 6" Wafer/fab	100 devices 70GHz (100Gbps) OEIC Int driver/TIA 50Gbps (50GHz) NRZ/PAM4-16 8" Wafer/fab	Purple Brick Wall	1000 devices 70GHz (400Gbps) Coherent client-side 8 & 12" Wafer/fab	Purple Brick Wall	10,000 devices OEIC Int driver/TIA 100Gbps (serial) Coherent DSP-less 15" Wafer/fab?
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Dielectric Photonics	100 devices 25GHz, 50GHz PIC Tx & Rx NRZ/PAM4 & NRZ/PAM4-8 6" Wafer/fab	1000 devices 70GHz OEIC Int driver/TIA 50GHz NRZ/PAM4-16 8" Wafer/fab	Purple Brick Wall	10,000 devices 70GHz Coherent client-side 8 & 12" Wafer/fab	Purple Brick Wall	100,000 devices OEIC Int driver/TIA 70GHz 15" Wafer/fab
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LIGHTWAVE LOGIC™
Tough to design
>1600Gbps+
modules
Design

Tough to design
>50GHz
bandwidth
devices

Easier for high
bandwidth
devices and
integration

LSI
challenges

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Source: Lightwave Logic

Can we penetrate the 'Purple Brick Wall'? Some technologies are suited for this...others need \$\$\$

2020 Roadmap

	2019	2020	2022	2024	2026	2028
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2020 Roadmap	2019	2020	2022	2024	2026	2028
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LIGHTWAVELOGIC™
Faster by Design



Polymers are additive to integrated photonics and hybrid platforms

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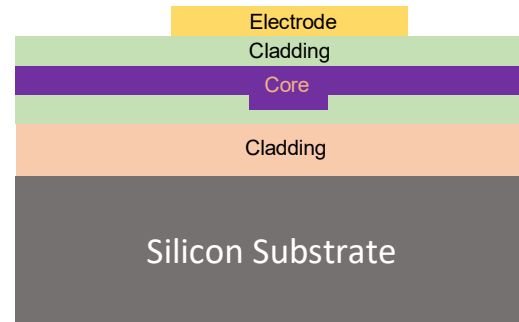
Source: Lightwave Logic

EO Polymers have low power and high bandwidth natural ability...

Electro-optic polymers for high-speed, low voltage

Active polymer is additive to semiconductor platforms to enhance performance

Polymer Stack™

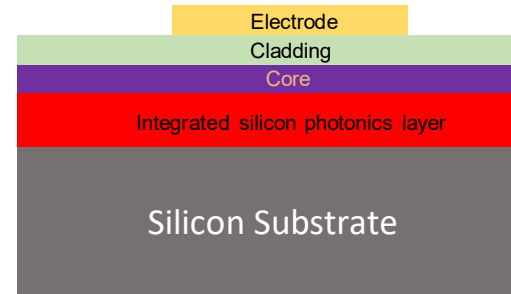


Classic!

Polymer stack modulator

- 3-layer polymer stack waveguides
- Linear Pockel's effect phase modulator (or Amplitude modulator if in Mach-Zehnder)
- Excellent high-speed performance (>70 GHz), low voltage ($\sim 1 \text{ V} \sqrt{\text{V}\pi}$), and high stability.
- Standard fab equipment & methods

Polymer Plus™

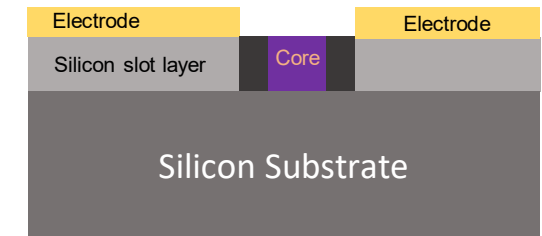


Additive!

Simpler and easier to integrate

- Minimizing polymer layers for integration of modulator with other devices in Si (or other) PIC
- Spin-on wafer-level hybrid integration

Polymer Slot™



Tiny!

Polymers in Si slot modulators

- Small size for highest integration levels
- Modulator device itself is hybrid silicon-EO Polymer (Silicon provides the waveguiding and electric field, EO polymer provides the high-speed EO functionality)

Polymer modulators...easy to fab, low power, fast, and flexible in performance



2022 Roadmap (Packaging)	2021	2022	2024	2026	2028	2030
Modules/TxRx Data rate density Form factor	400Gbps 25 Tbps/1U Q/OSFP	800Gbps OSFP/OBO/CP	100Tbps/1U OBO/CP	1600Gbps 400Tbps/1U Co-Pkg/CoB	3200Gbps 1600Tbps/1U Micro-Co-Pkg/CoB	
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Typical link reach Ind wish (@400Gbps) Industry plan	10-100m <\$1/Gbps	5-50m <\$0.5/Gbps \$1/Gbps	Purple Brick Wall	<\$0.25/Gbps Purple Brick Wall	1-25m \$0.25/Gbps	<\$0.05/Gbps \$0.15/Gbps
Traditional Gold Box	Butterfly 50GHz. Hermetic PIC	100GHz	micro-butterfly Purple Brick Wall	nano-butterfly 150GHz Purple Brick Wall	200GHz	
Surface mount	SOIC (<50 lead) 25GHz.	50GHz	micro-SOIC (<50 lead) 70GHz	70GHz (100Gbps NRZ) Purple Brick Wall	100GHz (130Gbps NRZ) Purple Brick Wall	
Chip-on-board	Flip-chip bump (100) 25GHz.	50GHz	1000 devices 70GHz	10000 devices 100GHz Purple Brick Wall	100,000 devices 200GHz Purple Brick Wall	
Co-packaging (layer 1 – chip on carrier)	2 chips 25GHz. Butt coupling Grating coupling	10 chips 50GHz	30 chips	70GHz Purple Brick Wall	70GHz Purple Brick Wall	50 chips 150GHz
Co-packaging (layer 2 - component)	10 devices 25GHz.	50GHz	100 devices	70GHz Purple Brick Wall	1000 devices 150GHz Purple Brick Wall	
	Normal Black Font = Reasonably expected based on current efforts		Purple Brick Wall = Technology cost barrier		Slanted Red Font = Major industry effort required for commercialization	

These boxes are empty – we could plan to fill them from a packaging standpoint...

Source: Lightwave Logic

Packaging roadmap for integrated photonics: who wants to volunteer?