



LIGHTWAVELOGIC™

*Faster by Design*

**Integrated photonics roadmaps: enabling high performance packaging**

**Michael Leppy, CEO, Lightwave Logic Inc.**

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The information in this presentation may contain forward-looking statements within the meaning of the Private Securities Litigation Reform Act of 1995. You can identify these statements by use of the words "may," "will," "should," "plans," "explores," "expects," "anticipates," "continue," "estimate," "project," "intend," and similar expressions. Forward-looking statements involve risks and uncertainties that could cause actual results to differ materially from those projected or anticipated. These risks and uncertainties include, but are not limited to, general economic and business conditions, effects of continued geopolitical unrest and regional conflicts, competition, changes in technology and methods of marketing, delays in completing various engineering and manufacturing programs, changes in customer order patterns, changes in product mix, continued success in technological advances and delivering technological innovations, shortages in components, production delays due to performance quality issues with outsourced components, and various other factors beyond the Company's control.

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



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

**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	<b>Purple Brick Wall</b> = 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?

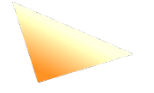


2020 Roadmap	2019	2020	2022	2024	2026	2028	
Modules/TxRx Data rate density Form factor	400Gbps 25 Tbps/1U Q/OSFP	800Gbps OSFP/OBO/CP	100Tbps/1U OBO/CP	1600Gbps Co-Pkg/CoB	400Tbps/1U Co-Pkg/CoB	3200Gbps 1600Tbps/1U Micro-Co-Pkg/CoB	1600Gbps+ modules
Typical link reach Ind wish (@400Gbps) Industry plan	<10km \$2/Gbps >\$5/Gbps (<2km)	<10km \$1/Gbps <\$2/Gbps	<2km \$0.5/Gbps	<2km \$0.5/Gbps	<2km \$0.2/Gbps	<2km \$0.2/Gbps	<\$1/Gbps
Typical link reach Ind wish (@400Gbps) Industry plan	10-100m <\$1/Gbps	5-50m <\$0.5/Gbps	1-25m <\$0.25/Gbps	1-25m \$0.2/Gbps	1-25m <\$0.05/Gbps	1-25m <\$0.15/Gbps	
InP Monolithic	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	10000 devices 90GHz OEIC Int driver/TIA NRZ/PAM4-16 4 & 6" Wafer/fab	10000 devices 90GHz OEIC Int driver/TIA Coherent client-side 4 & 6" Wafer/fab	10000 devices 100GHz OEIC Int driver/TIA Coherent client-side 8" Wafer/fab?	100,000 devices 100GHz OEIC ASIC 50Gbps (50GHz) 8" Wafer/fab?	90GHz devices?
SiP & InP/SiGe hybrid	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 70GHz (400Gbps) OEIC Int driver/TIA 100Gbps (serial) Coherent SP-less 15" Wafer/fab?	10,000 devices 100GHz (150Gbps serial) OEIC Int driver/TIA Coherent client-side 15" Wafer/fab?	70GHz devices?
Polymer Photonics	10 devices 25GHz, 50GHz (Laser-Mod) 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) NRZ/PAM4-16 4" Wafer/fab	1000 devices 100GHz (150Gbps serial) 50GHz OEIC Int driver/TIA NRZ/PAM4-16 4 & 6" Wafer/fab	10000 devices 100GHz (150Gbps serial) 50GHz OEIC Int driver/TIA Coherent client-side 8" Wafer/fab	10000 devices 100GHz (150Gbps serial) 50GHz OEIC Int driver/TIA (SiP/InP) Coherent client-side 8" Wafer/fab	10,000 devices 100GHz (150Gbps serial) OEIC ASIC 70GHz 15" Wafer/fab	100GHz devices
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GaAs (VCSEL)	100 devices 25GHz, 50GHz VCSEL PIC 25GHz NRZ/PAM4 & NRZ/PAM4-8 6" Wafer/fab	1000 devices 50GHz VCSEL PIC 50GHz NRZ/PAM4-16 6" Wafer/fab	10000 devices 70GHz OEIC Int driver/TIA 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 70GHz (VCSEL-Mod) VCSEL PIC 70GHz (100Gbps) Coherent client-side	1000 devices per chip
	Normal Black Font = Reasonably expected based on current efforts		Purple Brick Wall = Technology cost barrier		Slanted Red Font = Major industry effort required for commercialization		

Source: Lightwave Logic

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





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Typical link reach Ind wish (@400Gbps) Industry plan	<10km \$2/Gbps >\$5/Gbps (<2km)	<10km \$1/Gbps <\$2/Gbps	<2km Purple Brick Wall	<2km \$0.5/Gbps	<2km \$0.5/Gbps	<2km \$0.2/Gbps
Typical link reach Ind wish (@400Gbps) Industry plan	10-100m <\$1/Gbps	5-50m <\$0.5/Gbps	Purple Brick Wall	1-25m <\$0.25/Gbps	1-25m \$0.25/Gbps	<\$0.15/Gbps
<b>InP Monolithic</b>	100 devices 25GHz, 50GHz PIC WDM Tx & Rx (30GHz) NRZ/PAM4 3" Wafer/fab	1000 devices 70GHz OEIC Int driver/TIA 50Gbps (50GHz) NRZ/PAM4-8 4" Wafer/fab	Purple Brick Wall	10000 devices 90GHz OEIC Int driver/TIA 100Gbps (70GHz) NRZ/PAM4-16 4 & 6" Wafer/fab	Purple Brick Wall	100,000 devices 100GHz OEIC ASIC 50Gbps (50GHz) 8" Wafer/fab?
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Tough to design  
>1600Gbps+  
modules

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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LIGHTWAVELOGIC™  
Faster by Design



Polymers are additive to integrated photonics and hybrid platforms

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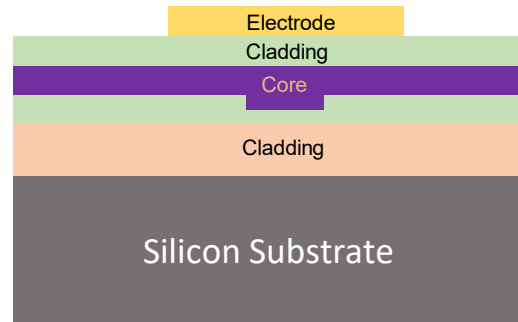
Source: Lightwave Logic

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™

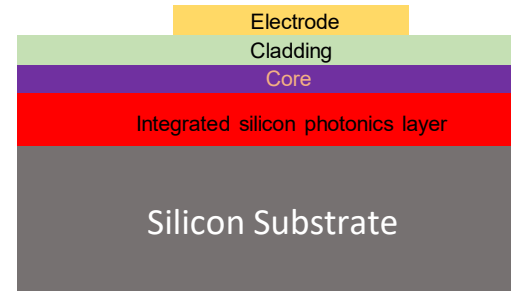


### Classic!

#### 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 ( $\sim 1 \text{ V V}\pi$ ), and high stability.
- Standard fab equipment & methods

## Polymer Plus™

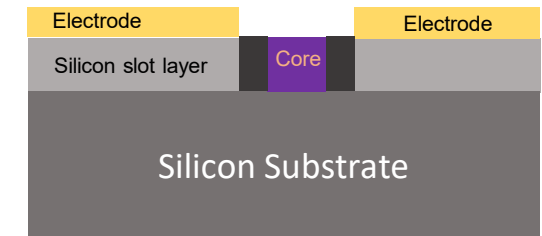


### Additive!

#### 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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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 & waferscale	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	

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

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Source: Lightwave Logic

Packaging roadmap for integrated photonics: who wants to volunteer?