

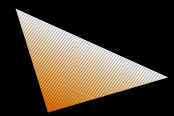


LIGHTWAVE LOGIC®

Faster by Design

Foundry based polymer optical modulators

Michael Lebbby, CEO
Lightwave Logic (NASDAQ:LWLG)



Safe harbor

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A server room with rows of black server racks. The scene is illuminated by vibrant, glowing light trails in shades of blue, orange, and purple that swirl and streak across the floor and racks, creating a sense of dynamic energy and data flow. The text "We are excited..." is centered in the foreground in a white, bold, sans-serif font.

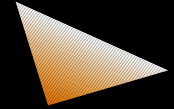
We are excited...

Ringling the Bell at NASDAQ (10th Sept 2021)

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Organic up-list...as promised in 2017...



NASDAQ 1yr Anniversary (1st Sept 2021)

LIGHTWAVE



1st Sept 2022: 1yr on NASDAQ

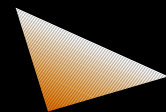
A server room with rows of black server racks. The scene is illuminated by vibrant, glowing light trails in shades of blue, orange, and purple, which appear to be moving through the space, creating a sense of dynamic energy and data flow. The text "4 takeaways..." is overlaid in the center in a white, sans-serif font.

4 takeaways...

- We have unique polymers...
- Our technology is ultra-fast, ultra-low power...
- We are positioned to have polymers become ubiquitous...
- Polymers are foundry compatible...

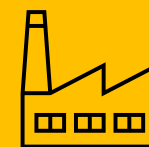
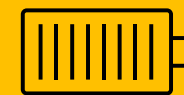


**Unique core
competences**



Polymer advantages

- Naturally very fast at modulating light (material properties)
 - 2-3X existing solutions using modulators
- Naturally very low power consuming (material properties)
 - 10X lower power depending on device/architectural design
- Foundry compatible: PDKs ported to silicon fabs
 - Process is standard and does not require special tool kits
 - Consistent, stable and reliable poling process
- EO Polymer has security of supply and scalable in vol
 - Material designed and sourced directly from LWLG
- Low-cost addition to integrated photonics platforms
 - Silicon photonics (and InP) can be boosted in performance

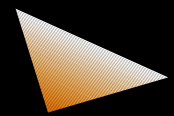


Polymers are unique in their properties

A server room with rows of black server racks. The scene is illuminated by vibrant, glowing light trails in shades of blue, orange, and purple, which appear to be moving through the space, suggesting data flow or network activity. The text "Hybrid PIC..." is overlaid in the center in a white, bold font.

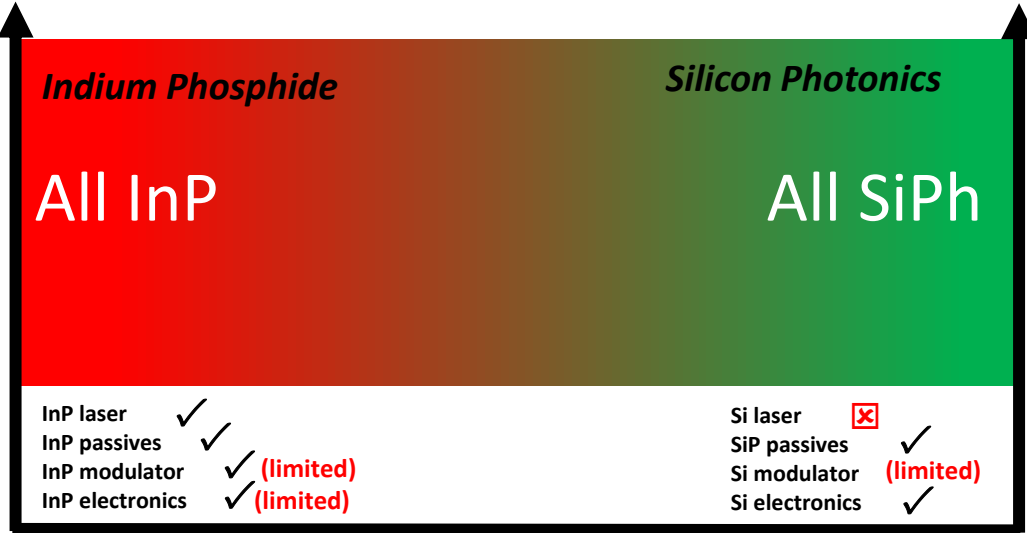
Hybrid PIC...

Fiber communications have 2 incumbent PICs, however...



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Incumbent *Incumbent*



Limited attributes

Limited attributes

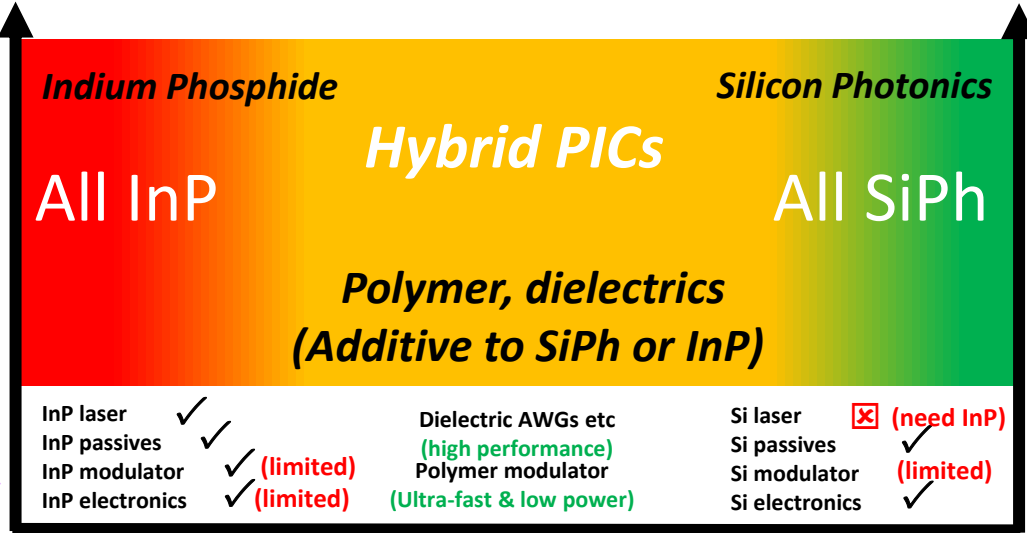
Incumbent technologies can't do everything monolithically...

Hybrid PICs increase performance...

New hybrid PICs

Incumbent

Incumbent

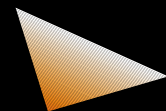


Limited attributes

Limited attributes



Hybrid PICs can boost performance of PICs



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
 - GaAs (Gallium Arsenide) → e.g. Hybrid PIC → GaAs + Si ICs

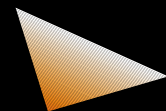
- ***New platforms for Hybrid PICs***

- *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...

A server room with rows of black server racks. The scene is illuminated by vibrant, glowing light trails in shades of blue, orange, and purple that swirl and flow through the aisle, creating a sense of dynamic energy and data movement. The text 'Foundry compatible?' is overlaid in the center in a bold, white font.

Foundry compatible?



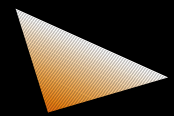
Foundry compatibility for PICs

New technology	Foundry compatibility
Polymers (modulators)	Silicon, InP, GaAs, others
Dielectrics (passives)	Silicon, InP, GaAs, others
Silica (passives)	Silicon, InP, GaAs, others
Glass (passives)	Silicon, InP, GaAs, others
Thin Film Lithium Niobate (modulators)	LiNoB, silicon (?)
Metal/plasmonic (modulators)	Silicon, InP, others
Barium Titanate (modulators)	Silicon (?)
Germanium (detectors)	Silicon, GaAs
Gallium Nitride (LEDs, lasers)	GaN, silicon (?)
Graphene (detectors)	Silicon (?)

Silicon offers best opportunities to scale volume quickly and efficiently

A server room with rows of black server racks. The room is dimly lit, with a grid ceiling. Overlaid on the scene are vibrant, glowing light trails in shades of blue, orange, and purple, swirling and streaking across the floor and racks, suggesting data flow or optical signals.

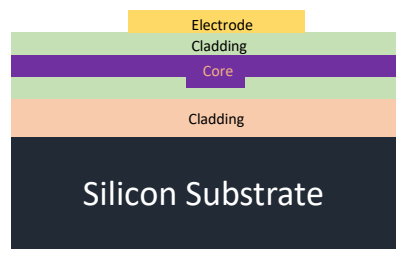
Electro-optic polymers



Natural integration with big foundries

Additive to semiconductor platforms (SiPh, InP...) to enhance performance

Polymer Stack™

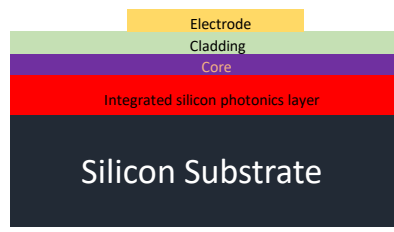


Classic!

Polymer stack modulator

- 3-layer polymer stack waveguides
- Excellent high-speed performance and high stability.
- Standard fab equipment & methods

Polymer Plus™

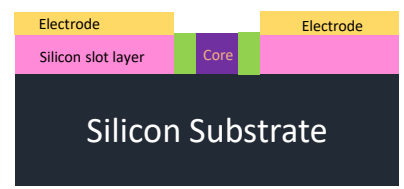


Additive!

Simpler and easier to integrate

- Minimizing polymer layers for integration of modulator with other devices in Si (or other) PIC platform
- Natural integration with PDK of silicon foundries

Polymer Slot™



Tiny!

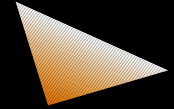
Polymers in Si slot modulators

- Small size for highest integration levels
- Natural integration with PDK of silicon foundries

Turbo-charge your silicon photonics & integrated photonics with polymers...

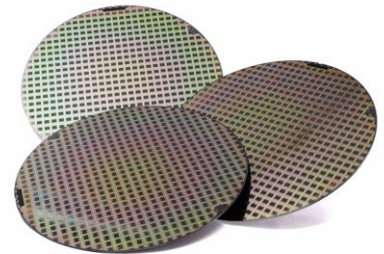
A server room with rows of black server racks. The scene is illuminated by vibrant, glowing light trails in shades of blue, orange, and purple that swirl and streak across the floor and racks, creating a sense of dynamic energy and data flow. The text 'Foundry scaling' is centered in the foreground in a white, bold, sans-serif font.

Foundry scaling

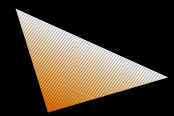


Partnering for success

- Partnering with multiple **foundries**, packaging partners and module/transceiver partners to position LWLG for future high-volume production
- Partnering to **qualify** polymer Process Development Kits (PDK) with foundries using standard fabrication techniques
- Technology evaluation & feedback
- Partnering for **licensing** the use of polymer materials that have been sourced, supplied and manufactured by LWLG
- Partnering for **technology transfer** of fabrication and device design to manufacturing facilities and foundries



Partnering allows us to focus on our uniqueness, efficient use of capital, & to prepare for volume...



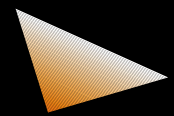
Volume scale with silicon foundries *with timelines*

L I G H T W A V E

Foundry	Geographical location	Wafers	Existing PIC PDK (silicon photonics, InP)	Open to create EO polymer PDK	Expected results
Foundry A (polymer plus)	North America	Silicon	Yes	In progress	2H22-1H23
Foundry B (polymer plus)	North America	Silicon	Yes	In progress	2H22-1H23
Foundry C (polymer plus)	Europe	Silicon	Yes	In progress	2H22-1H23
Foundry D (polymer slot)	North America	Silicon	Yes	In progress	2H22
Foundry E (polymer slot)	Europe	Silicon	Yes	In progress	2H22
Foundry F (polymer slot) – in discussion	North America	Silicon	Yes	Planned	2023
Foundry G (polymer slot) – in discussion	Europe	InP	Yes	Planned	2023

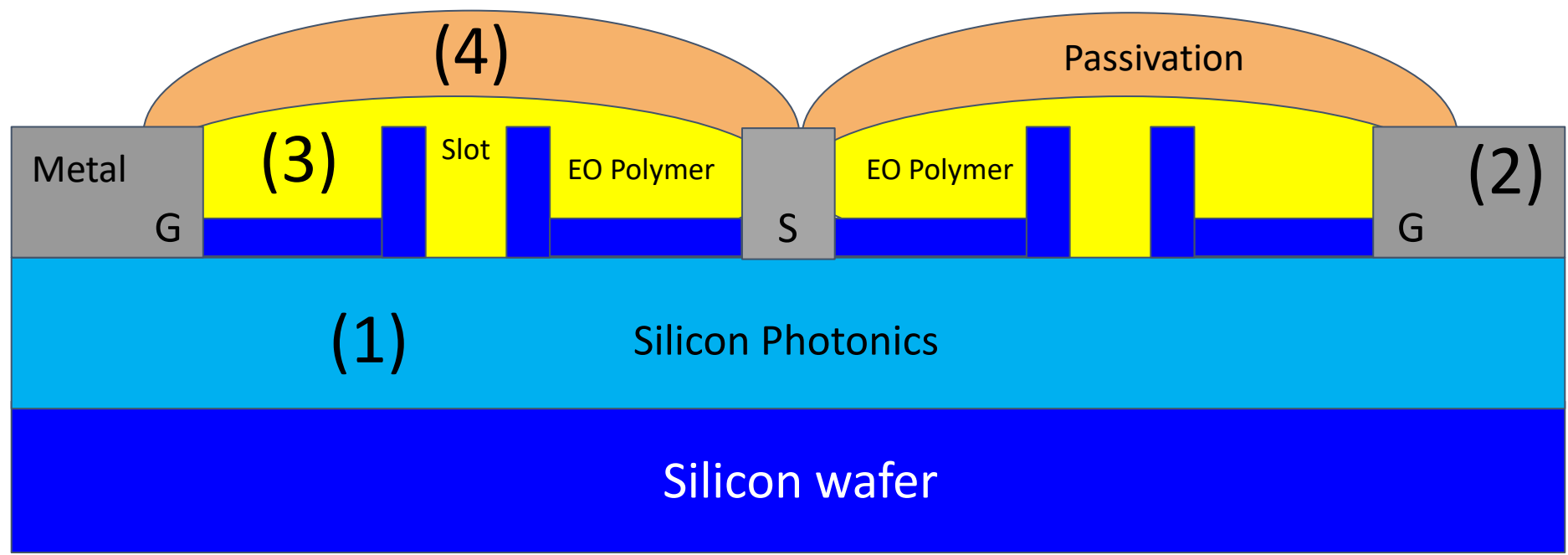
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Deep activities with foundries for volume scaling

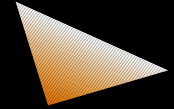


CMOS/silicon compatible PDK → Polymer Slot™

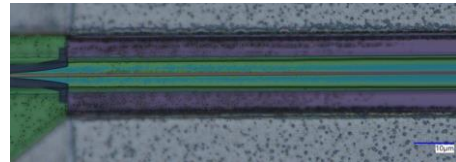
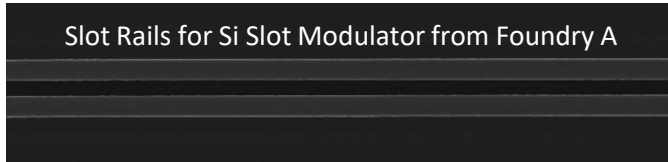
- (1) Standard CMOS/silicon photonics chip with slots defined by photolithography
- (2) Standard metallization for gate/source contacts
- (3) Spin-on EO polymer, cured in standard ovens, polled for optical switching
- (4) Dielectric passivation for protection to environment (chip-scale packaging)
- (5) Standardized, consistent poling process with extremely high yields



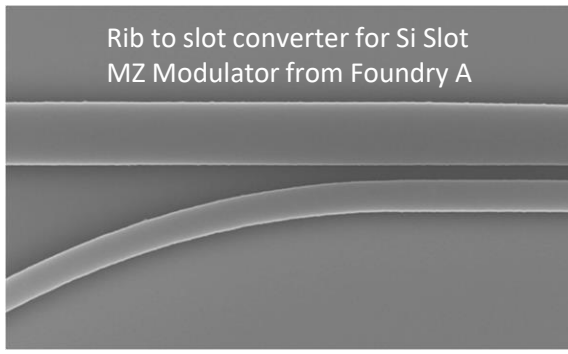
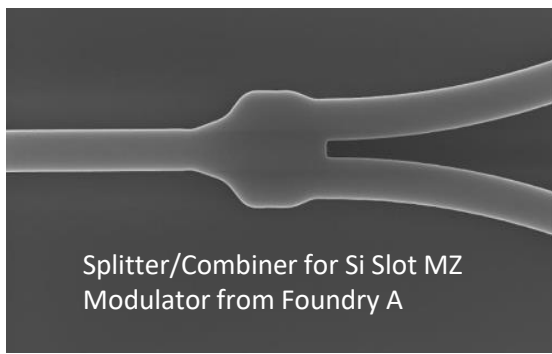
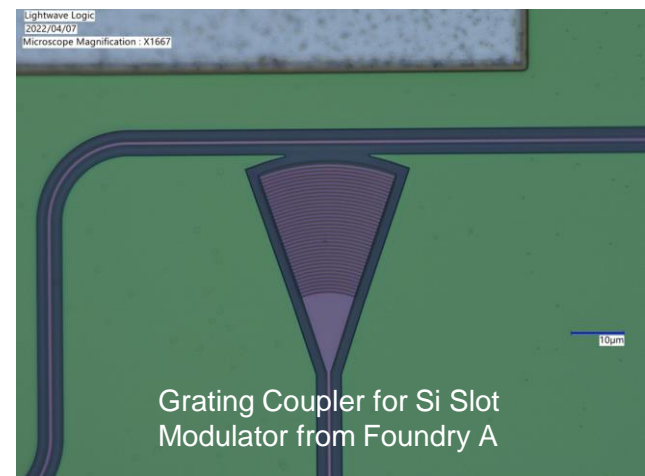
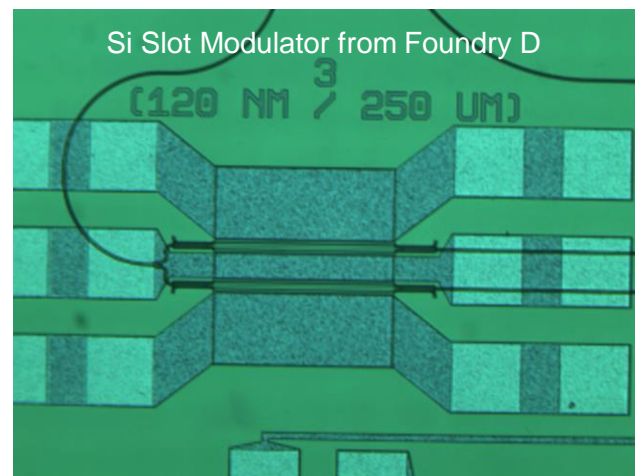
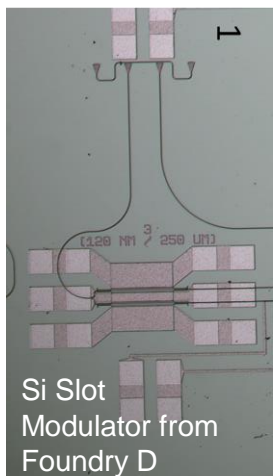
Standard silicon fabrication processes; standard silicon tools



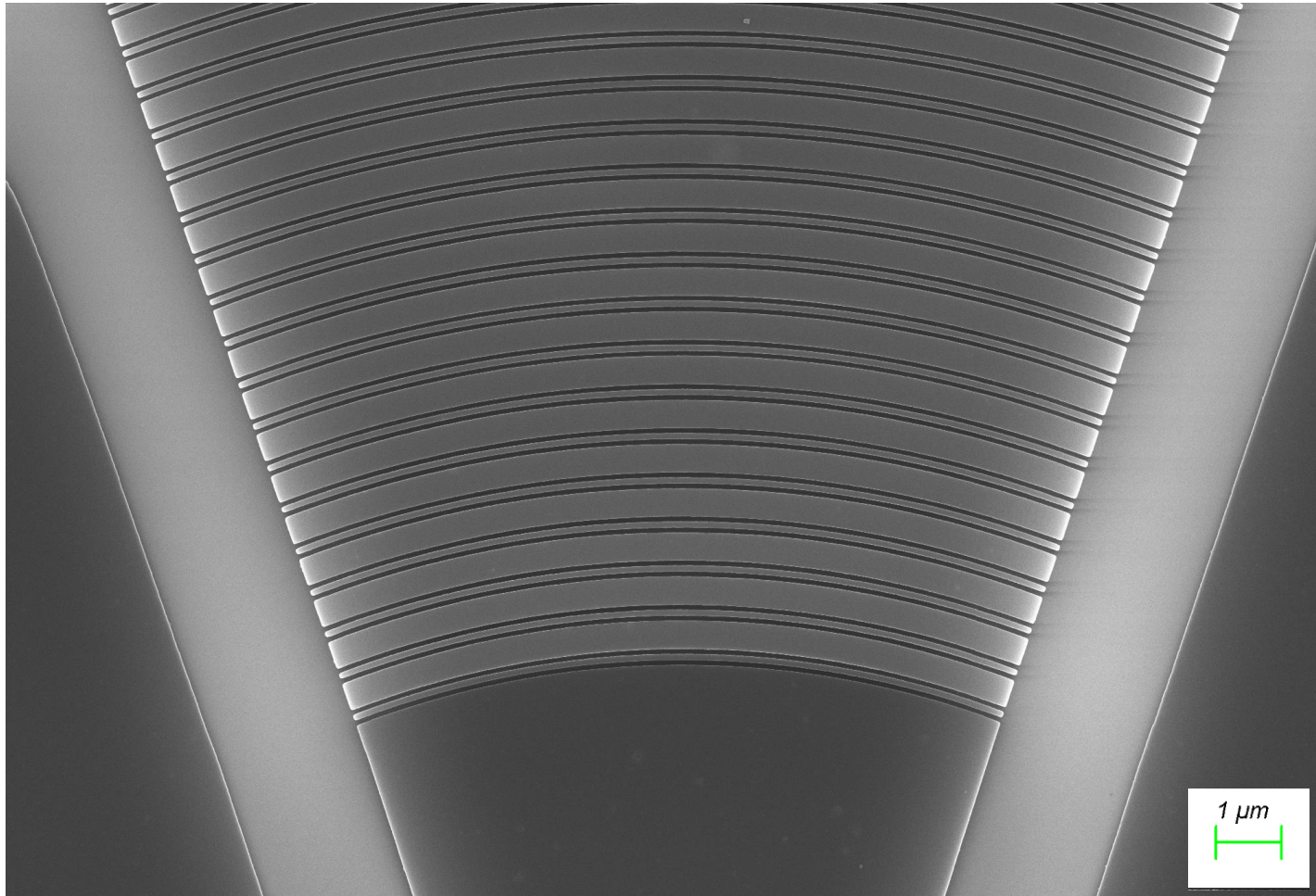
Foundry fabrication with PDK



Optical Microscope image of strip to rib converter + slot waveguide from Foundry D



Standard silicon fabrication components...

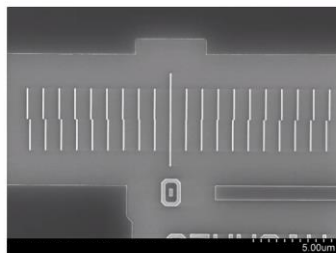
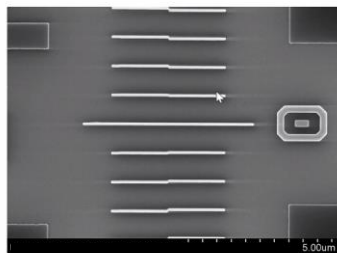


Vertical grating coupler example

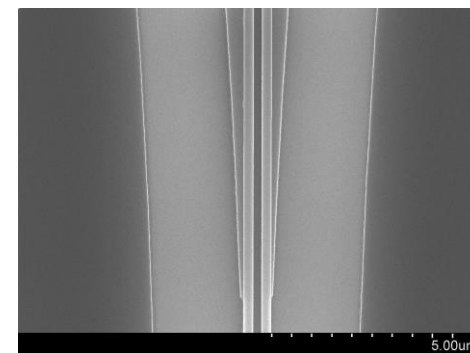
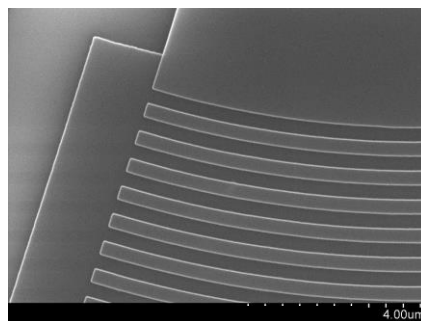


Polymer slot – foundry processing

Pilot Wafer SEM Images

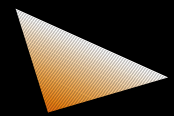


Verniers: better than 20 nm alignment



Grating Couplers and straight waveguides with good (standard) roughness and Strip-to-slot converters with good definition

Foundry quality, alignment, fabrication



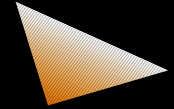
Poling for foundries

- Unique EO performance of poled polymers
 - For example: Bandwidths in excess of 100GHz, phase velocity match allowing bandwidths of 170GHz+, Low V_{pi} , High r_{33} ...
- Polymers are stable and reliable
 - The same arguments were made against LCDs and OLEDs and now we use OLED TVs, mobile displays....and we never discuss stability, reliability issues today...ever...
- Today, poling is a process that is consistent, stable and reliable and suitable for foundry operation
 - Advanced process, excellent control, standardized technique
 - Extremely high yields on >1000 poled devices...

Poling can be ported to foundries to simplify PDK processes

A server room with rows of black server racks. The scene is illuminated with vibrant, glowing light trails in shades of blue, orange, and purple, creating a sense of motion and data flow. The text is overlaid in the center of the image.

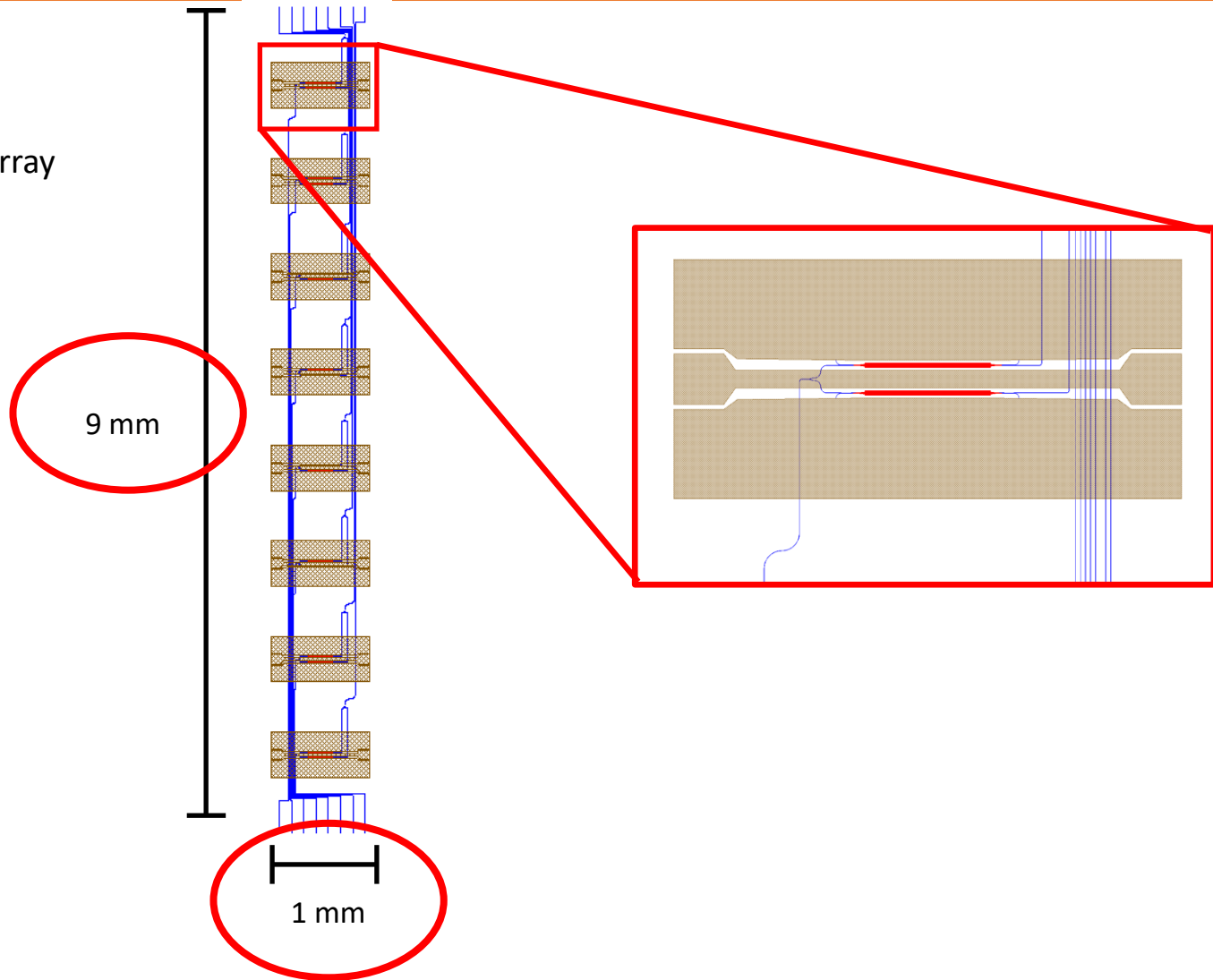
**Polymers modulators are
tiny...**



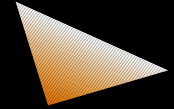
Polymer slot modulators are very small

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LWLG
8 x 1 Polymer Slot™ array

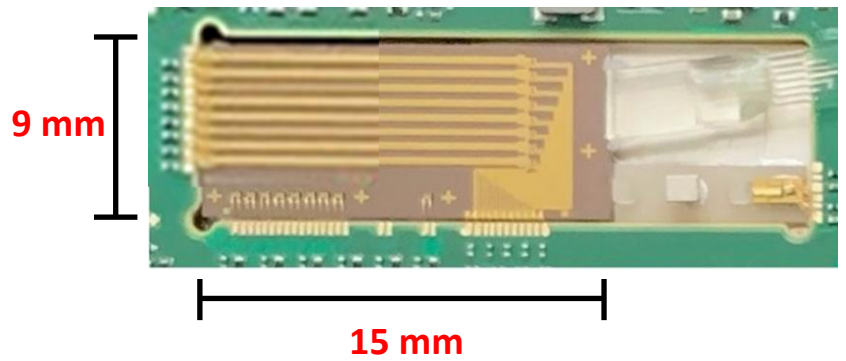


Size matters!



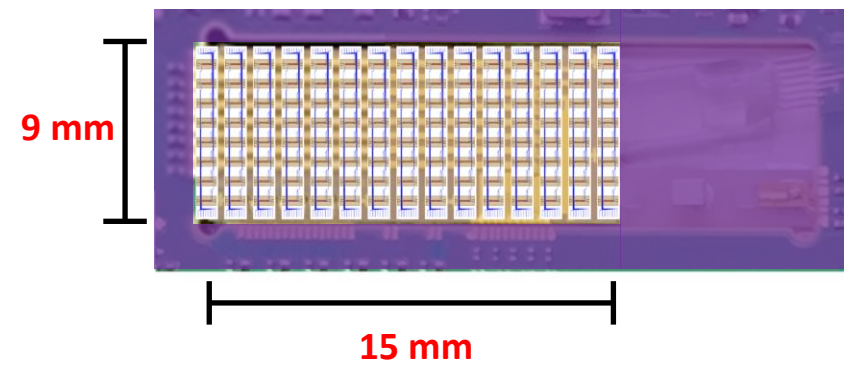
Only 30X better* ...

Competitive transceiver TFNL 800G-DR8 Module



8 modulators x 100G = 800G or 0.8T

Polymer Slot™



120 modulators x 100G = 12T
 120 modulators x 200G = 24T

Potential for 30x data capacity in same pluggable formfactor

At least 30X better than competition...size, low power, and speed matter...

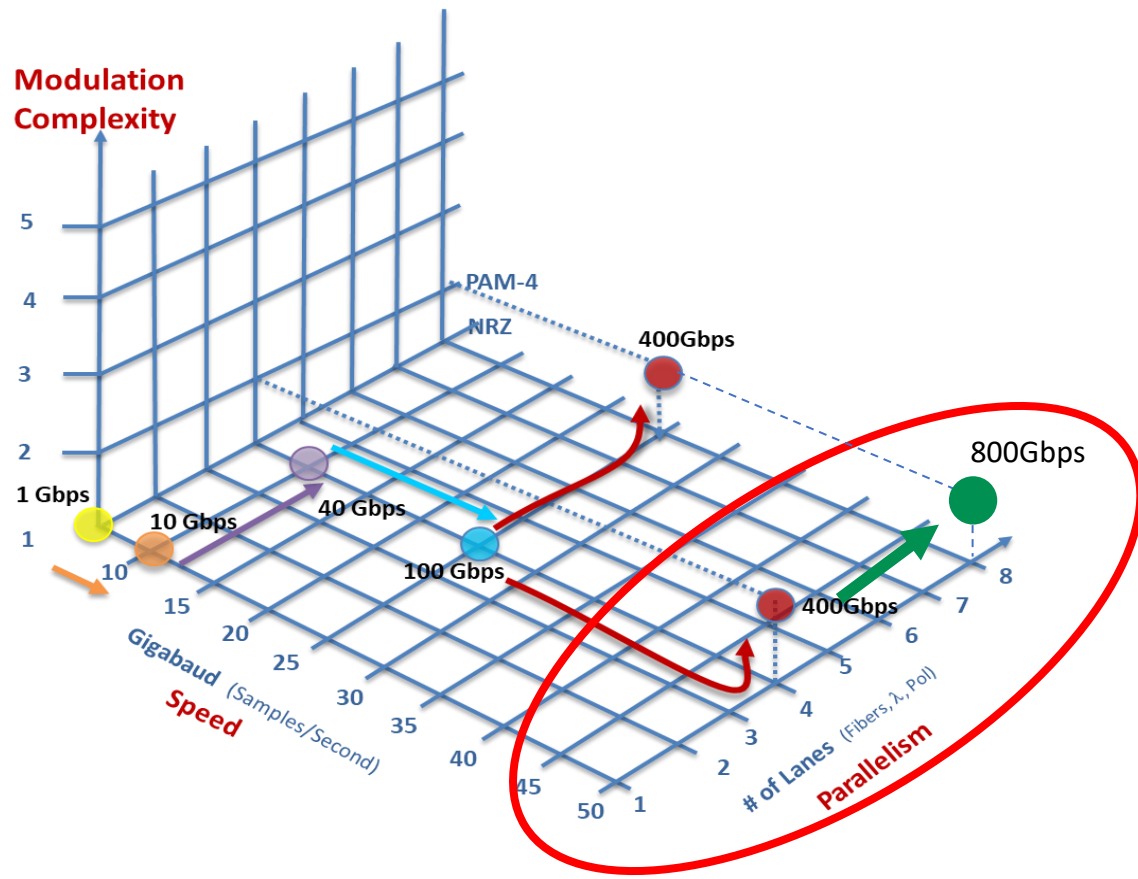
Source: Lightwave Logic (LWLG), Hyperlight (2022); *Density can be increased a factor of 2 giving ~60X capacity improvement towards 50T

A server room with rows of black server racks. The scene is illuminated with vibrant, glowing light trails in shades of blue and orange, suggesting high-speed data flow or advanced technology. The text is centered over the image.

**Polymers break the
speed limit...**

Historical perspective

- 1Gbps: 1 lane x 1Gbps (1990s) Easy
- 10Gbps: 1 lane x 10Gbps (circa 1999-2000) Easy
- 40Gbps: 4 lane x 10Gbps (early 2000s) Tougher
- 100Gbps: 4 lane x 25Gbps (early 2010s) Difficult
- 400Gbps: 4 lane x 50Gbps PAM4
 400Gbps: 8 lane x 25Gbps PAM4 (2015 onwards) More difficult
- 800Gbps: 4 lane x 100Gbps PAM4
 800Gbps: 8 lane x 50Gbps PAM4 (2022 onwards) Much more difficult
- 1600Gbps: 8 lane x 100Gbps PAM4



Increasing data rates becomes more and more difficult...

Traffic capacity: road analogy

Good roads: Faster cars:
more traffic capacity



More lanes: more traffic capacity



We already did the easy things like paving the road, and adding more lanes (WDM)...

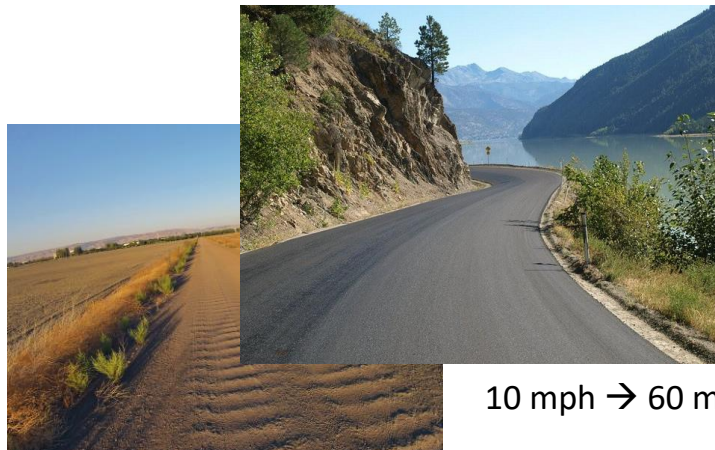
Traffic handling: road analogy

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Industry has done the hard stuff like 'encoding' and 'higher order modulation'

What about speed?



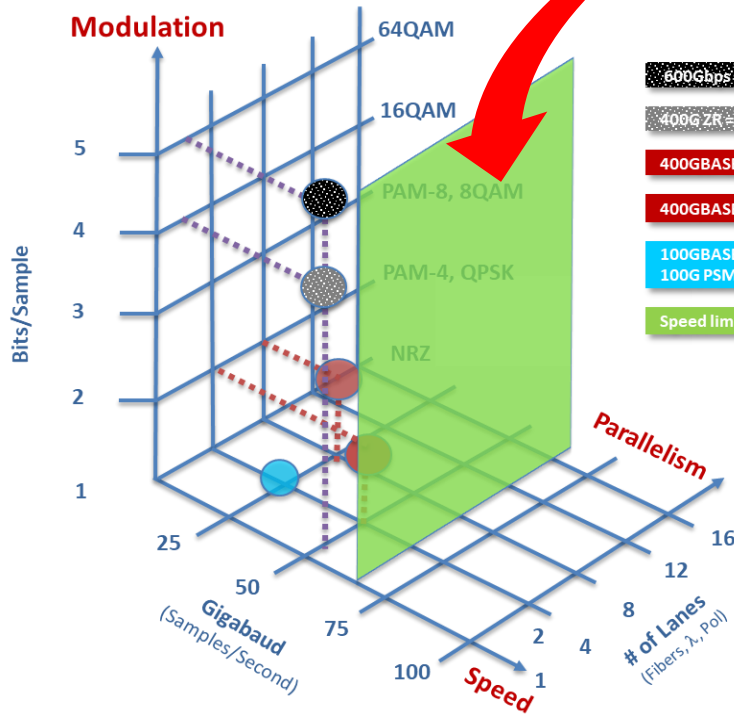
10 mph → 60 mph



Still ~60 mph

Speed has hit a plateau...

Speed limited by conventional photonics

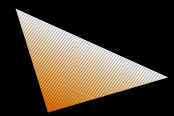


- 600Gbps = 64 Gbaud, 64QAM, 2 polarizations
- 400G ZR = 50 Gbaud, 16QAM, 2 polarizations
- 400GBASE-DR4/ 400G FR4 = 50 Gbaud, PAM4, 4 wavelengths
- 400GBASE-LR8 = 25 Gbaud, PAM4, 8 wavelengths
- 100GBASE-LR4/100G CWDM4 = 25 Gbaud, NRZ, 4 wavelengths
- 100G PSM4 = 25 Gbaud, NRZ, 4 fibers
- Speed limitation of optical devices



In optical analog metrics of GHz, >35GHz things get tougher...devices are tricky to design

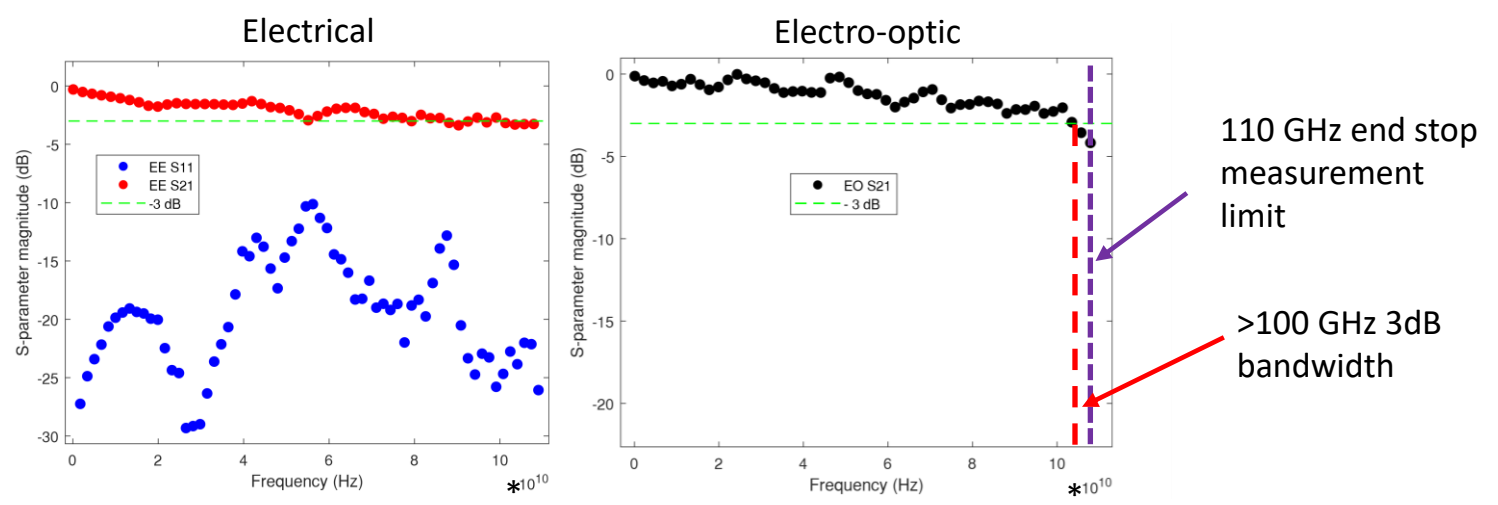
Speed limited in optical devices by device physics...requires innovation...



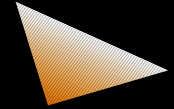
Super high optical bandwidth modulators

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Recent high-frequency S-parameter data from polymer modulators



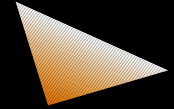
Super high performance > 100GHz S21 EO 3dB bandwidth



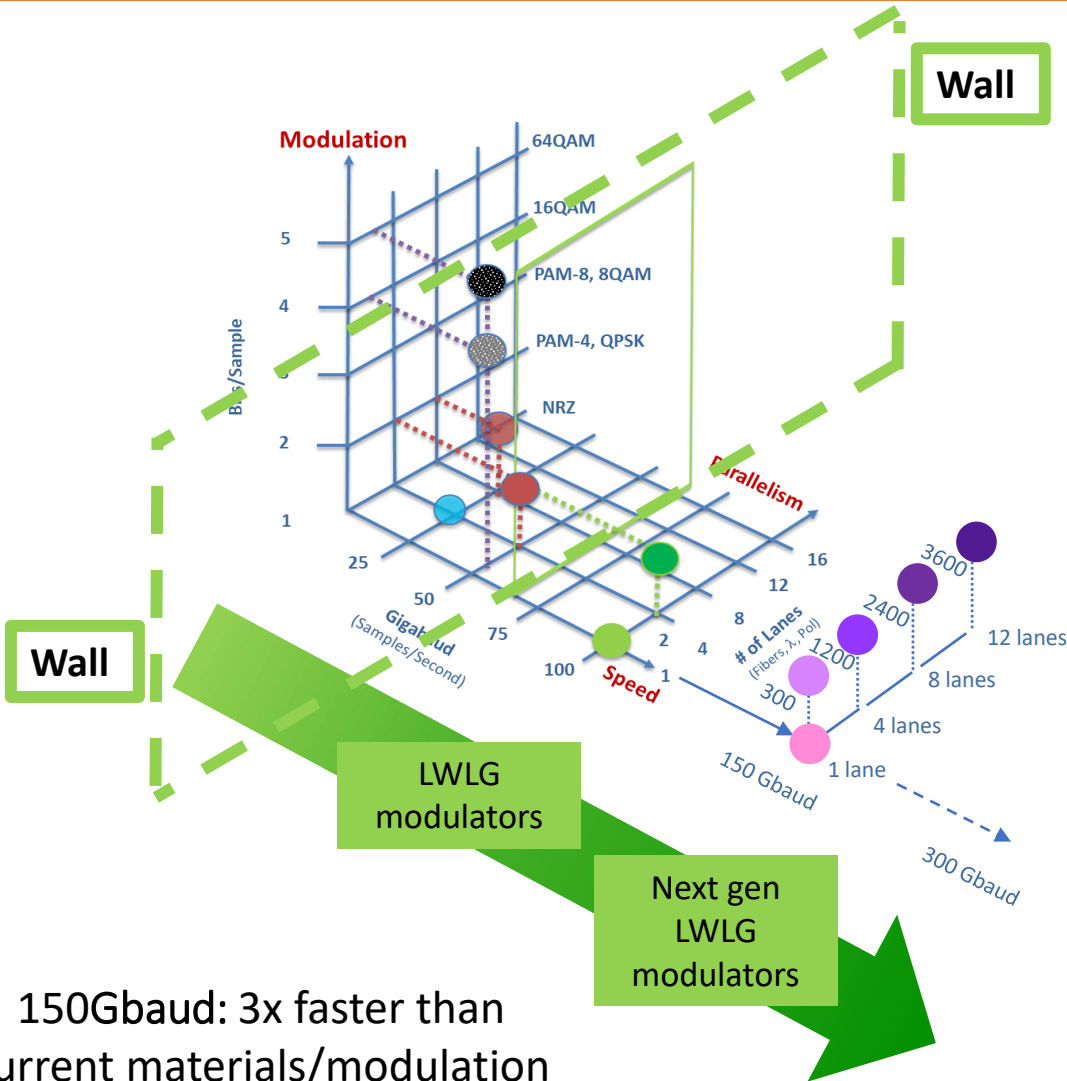
Ultra-fast polymers break the speed limit...



Polymers increase data rates as their bandwidths are 70GHz, 100GHz and beyond...



Our polymers break through the *speed wall*

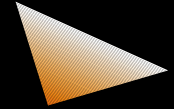


150Gbaud: 3x faster than current materials/modulation

Ultra-fast speed...

Data rates after breaking through the wall...

- 100Gbps = 100Gbaud, NRZ, 1 lane
- 800Gbps = 100Gbaud, PAM4, 4 lanes
- 150Gbps = 150Gbaud, NRZ, 1 lane
- 300Gbps = 150Gbaud, PAM4, 1 lane
- 1200Gbps = 150Gbaud, PAM4, 4 lanes
- 2400Gbps = 150Gbaud, PAM4, 8 lanes
- 3600Gbps = 150Gbaud, PAM4, 12 lanes



Where we enter the market...

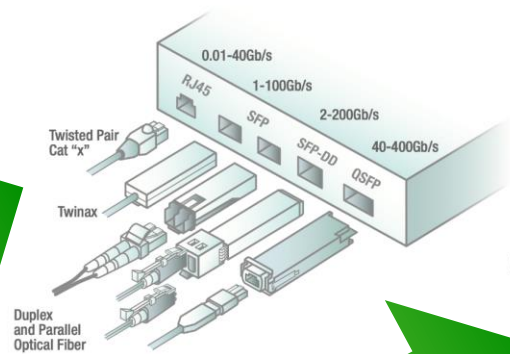
FORM FACTORS

Polymer modulators fabricated in silicon foundries

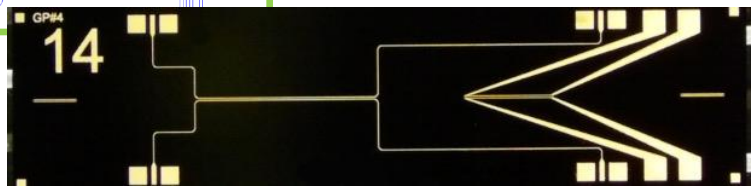
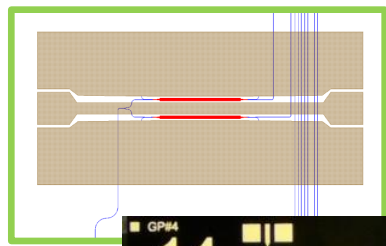
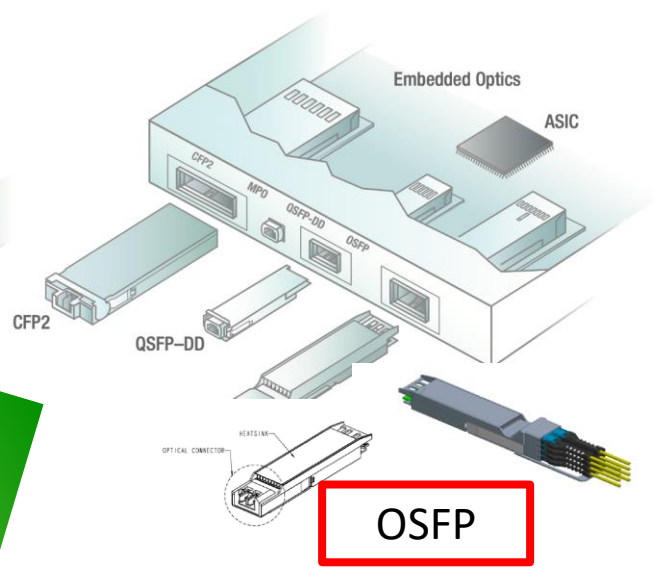
This diagram shows the most common form factors used in Ethernet ports. Hundreds of millions of RJ45 ports are sold a year while tens of millions of SFP and millions of QSFP ports ship a year.

This diagram shows new form factors initially designed for 100GbE and 400GbE Ethernet ports.

1-4 Lane Interfaces

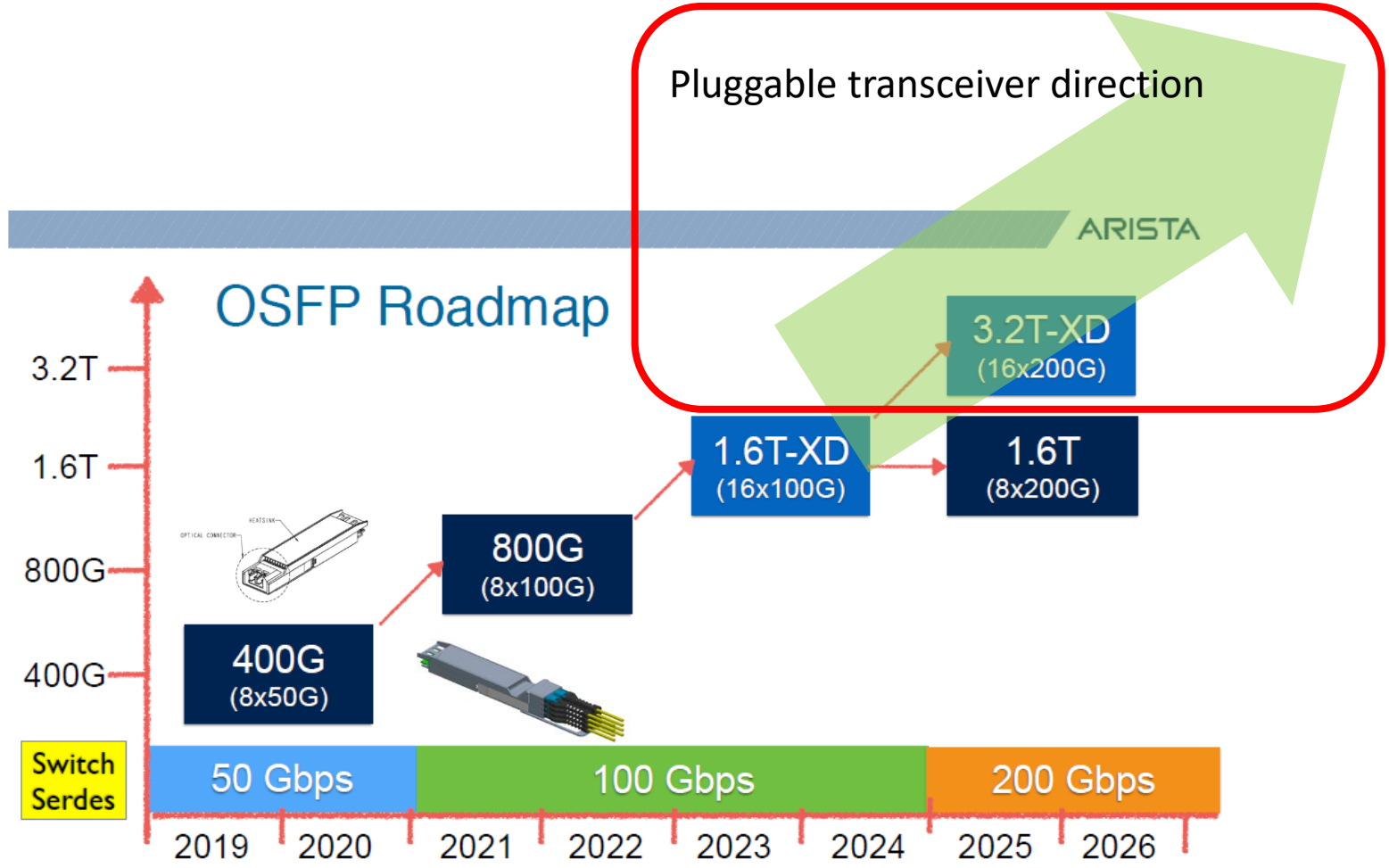


4+ Lane Interfaces



Polymer engines for pluggable transceivers

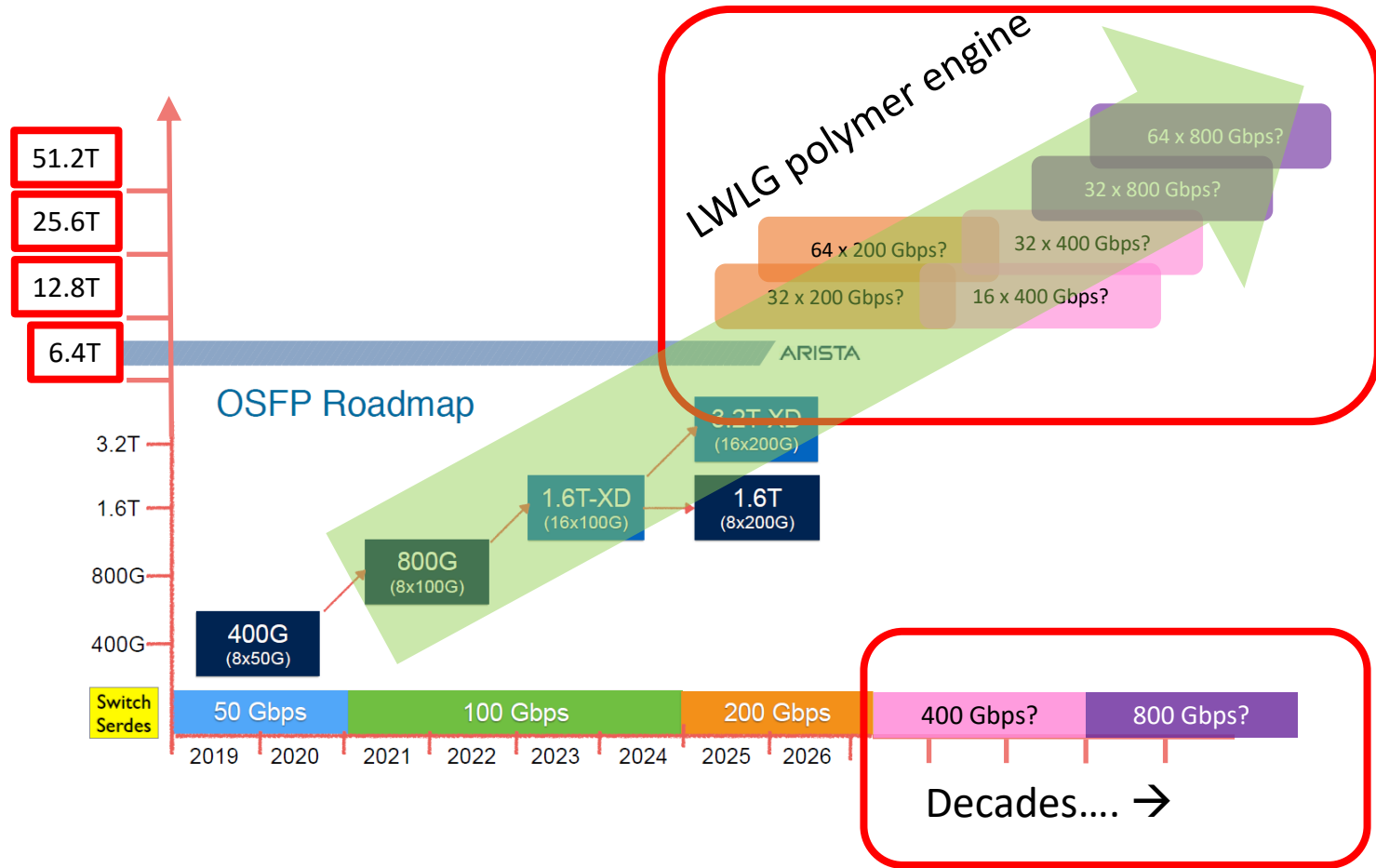
Optical transceiver trends



Pluggable transceivers need to increase in speed in conjunction with the electronics

Source: Adapted from Arista (2022), Lightwave Logic (LWLG), OSFP MSA (2022)

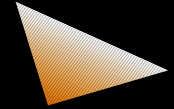
Polymers for decades...



Roadmap enabled by high speed, low power, tiny footprint polymers...

A server room with rows of black server racks. The scene is dark, with vibrant, glowing light trails in shades of blue, orange, and purple swirling through the air, suggesting data flow or energy. The text "Polymers are low power" is overlaid in the center in a bold, white font.

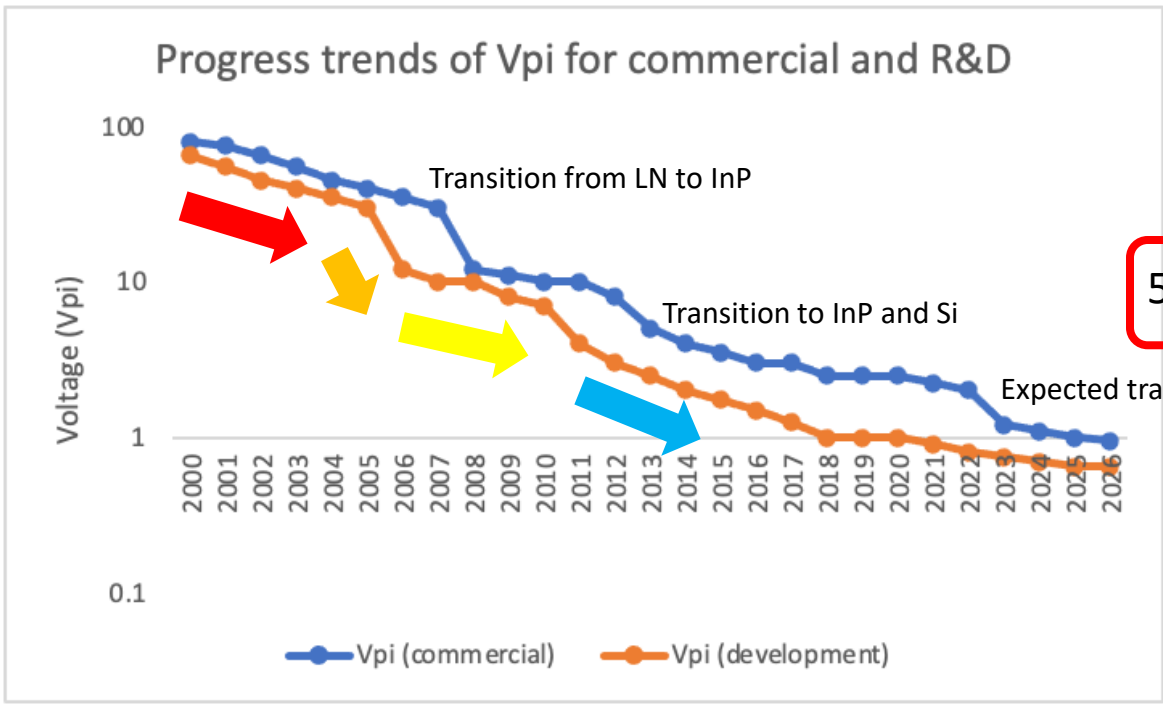
Polymers are low power



Ultra-low voltage polymers save power...

LIGHTWAVE

- Low voltage polymers -----Modulators can be driven directly from CMOS
- Lower voltage operation -----Saves power (~2-3X at device level)
- Less IC chips/drivers on the line card -----Lowers power and cost (~5-10X at board level)



Key

- Power hungry
- High power
- Moderate power
- Low power

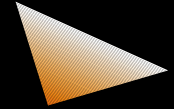
5V → 3V → 1V

Commercial progress trails development progress ~5yrs

Transition to polymer is coming as low power issues become dominant

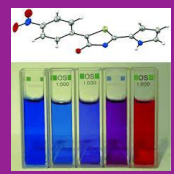
A server room with rows of black server racks. The scene is illuminated by vibrant, glowing light trails in shades of blue, orange, and purple that swirl and flow through the aisle, creating a sense of dynamic energy and data movement. The racks are filled with server components, and the overall atmosphere is futuristic and high-tech.

Summary



Summary...

Material Science



Standard fabrication & testing



High speed device design & packaging



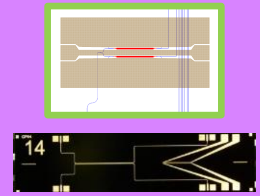
Powerful patent portfolio



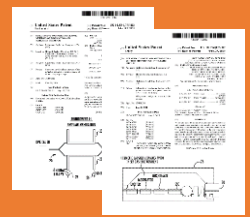
Huge \$B markets

Product	Revenue (\$M)	Units (Millions)	Price (\$)	Market	Key Applications
Fiber optics	~40,000	1.7k	~500,000	Passivity, 100% US Mfg	Core/edge, strong growth
MEMS devices	~10,000	100	~100,000	Passivity, 100% US Mfg	Core/edge, strong growth
ASICs/ASICs	~10,000	200	~100,000	Passivity, 100% US Mfg	Core/edge, strong growth
ASICs/ASICs	~10,000	100	~100,000	Passivity, 100% US Mfg	Core/edge, strong growth
ASICs/ASICs	~10,000	100	~100,000	Passivity, 100% US Mfg	Core/edge, strong growth
ASICs/ASICs	~10,000	100	~100,000	Passivity, 100% US Mfg	Core/edge, strong growth
ASICs/ASICs	~10,000	100	~100,000	Passivity, 100% US Mfg	Core/edge, strong growth
ASICs/ASICs	~10,000	100	~100,000	Passivity, 100% US Mfg	Core/edge, strong growth
ASICs/ASICs	~10,000	100	~100,000	Passivity, 100% US Mfg	Core/edge, strong growth
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Selling components



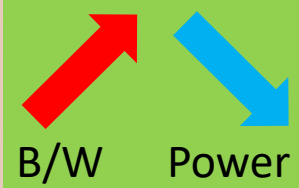
Licensing polymer materials



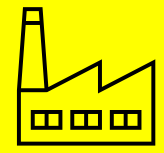
Technology transfer (to foundries)



Solving key internet Achilles Heels



Volume scale with silicon foundries



- We have *unique* polymers...
- Our technology is *ultra*-fast and *ultra*-low power...
- We are positioned to have polymers become *ubiquitous*...
- Polymers are *foundry compatible*...

Investor Relations Contact

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Thank you!

