POET Technologies

Synopsis Photonics Symposium

Extending Wafer Level Chip Scale Packaging (WLCSP) to Photonics using Photonics Interposers

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Topics

- Introduction
- Application Proof Points
- Conclusions

Photonics is undergoing a revolution today, in much the same way as VLSI underwent a revolution these past three decades.

Silicon Based Integration platforms are the key to the predicted explosion in growth

Data Centers
(Optical Connectivity)

Millions/Year

Compute
(Chip to Chip communication)

Automobiles
(LIDAR)

100s of Millions/Year

Wearables
(Healthcare)

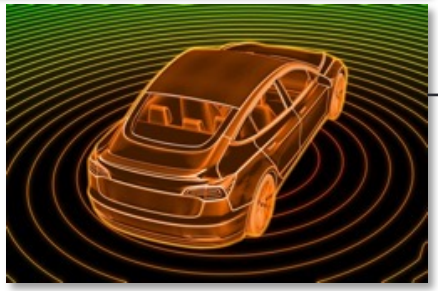
Smartphones
(Healthcare, Sensing)

Billions/Year

POET Technologies

Key challenges in Photonics

Millions/Year



100s of Millions/Year

Billions/Year

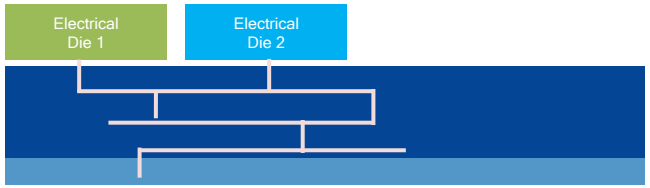
Current technologies are not scalable for applications needing 100's of millions and billions of units per year

VECTOR	CURRENT TECHNOLOGIES	POET	REASON
Unit Volume	✗	✓	Manufacturing, test and packaging is fully automated
Size	✗	✓	Components are integrated into a single chip
Cost	✗	✓	Everything is done at wafer-scale with semiconductor technology
Power Consumption	✗	✓	Components are fully integrated electrically and optically

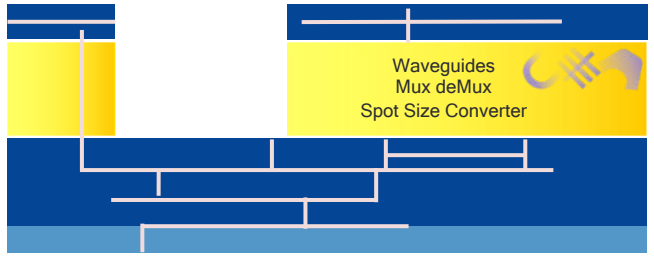
POET's Technology Solution – Photonics Interposers

The POET Optical Interposer is the first-ever chip-scale hybrid integration of electronics and photonics into a single chip using wafer-level processing, assembly, test

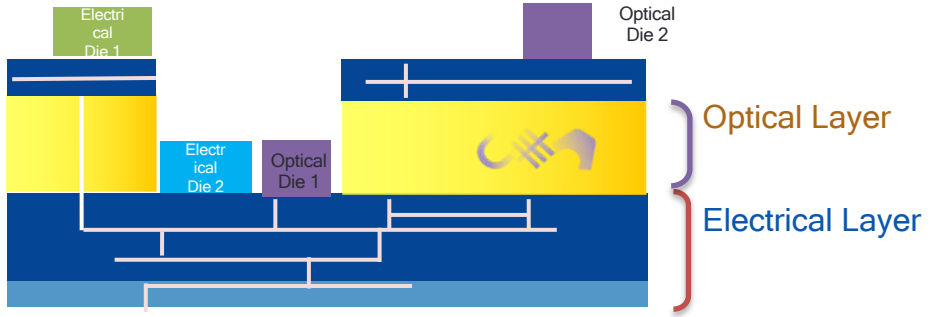
An Electrical Interposer



POET Optical Interposer



POET Optical Engine

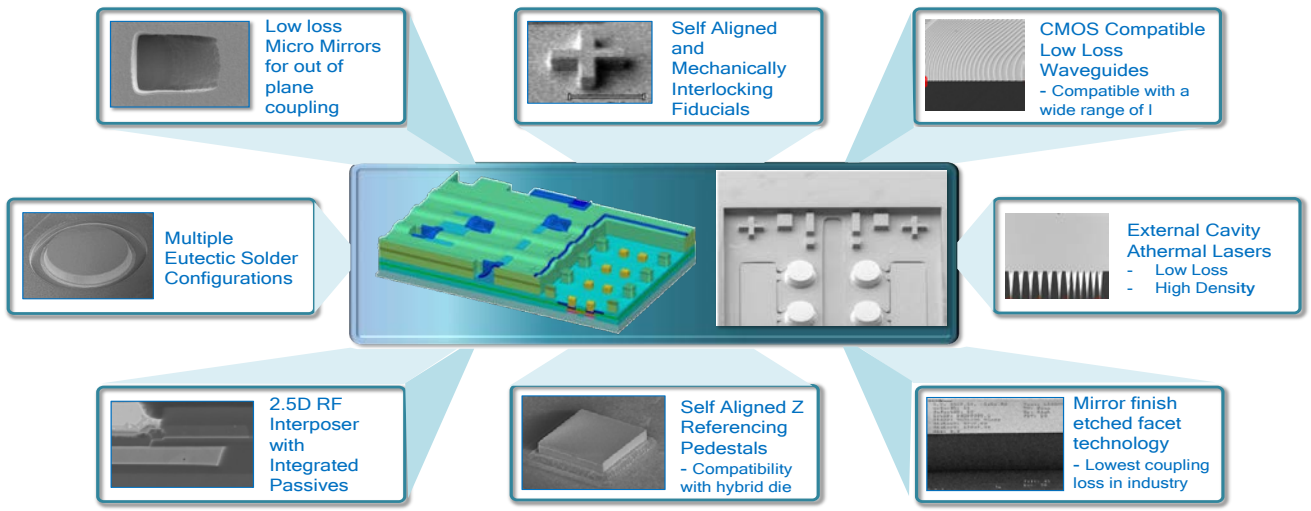


- Chip-Scale: integrated into a single chip on a standard silicon wafer.
- Hybrid: Use "known-good" and "best-of-breed" components made from different materials.
- Wafer-Level: All processes are done on full wafers, 100's at a time, rather than one at a time, in an automated process.

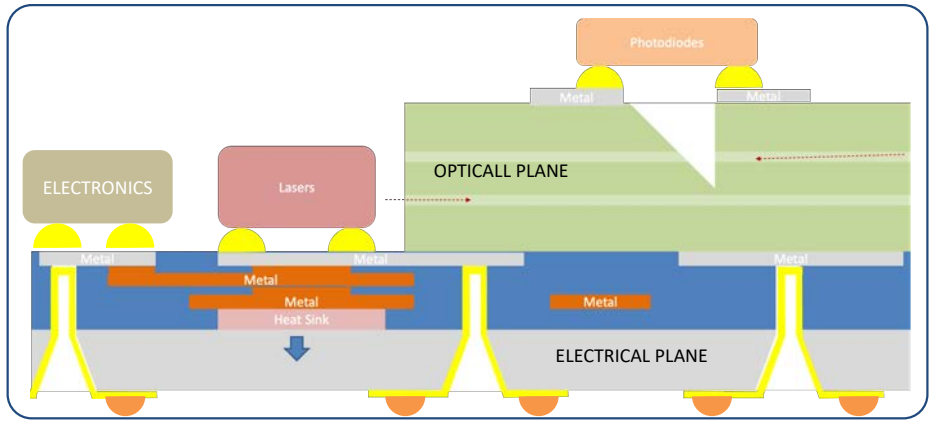
✓ *NO Active Alignment of Components* ✓ *ALL done with automated semiconductor equipment at wafer-level* ✓ *FULL integration of components*

POET's Optical Interposer

POET's Optical Interposer : A Co-Packaging Solution



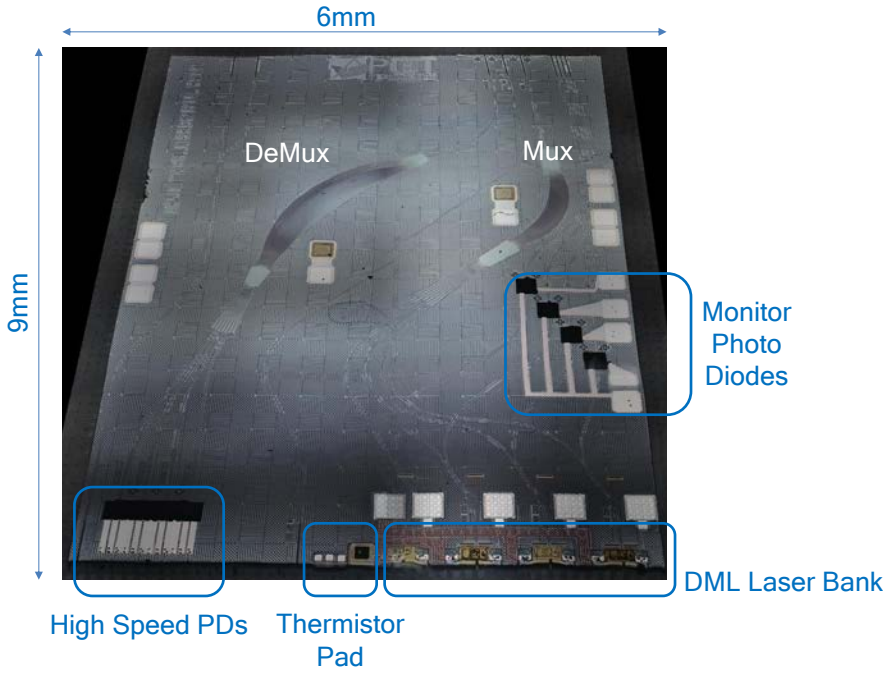
POET's Optical Interposer Platform is the most versatile photonics packaging platform in the Industry



- Two layers of low loss optical interconnects
- Multiple electrical redistribution layers with low RF insertion loss
- High throughput visually assisted passive "pick and place" assembly of electronics and photonics ICs and components
- In plane and Out of plane Optical Interfaces

Implementation into a 100G-400G Optical Engine

World's smallest CSP implementation of optical engines for 100-400G communications and beyond



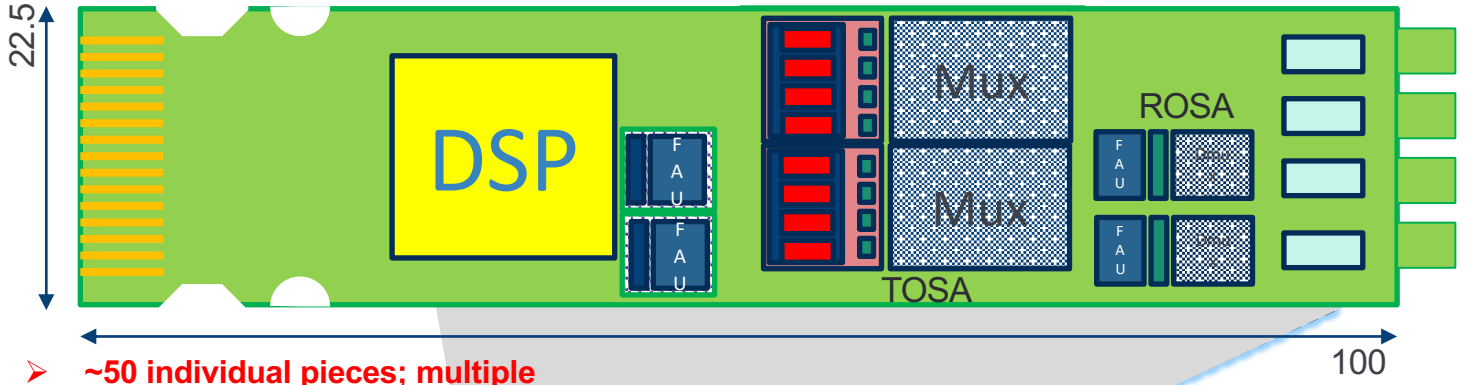
Simplified Design, Improved Energy and Lower Cost

Data Communications Challenges

- Serial data communication channels have not been able to keep up with the pace of bandwidth growth.
- Number of communications lanes increase as data rate increases!

Data Rate	Number of lanes
10G	1
40G	4
100G	1/4
200G	4
400G	4
800G	**8**
1.6T	**8/16**
3.2T	**16**

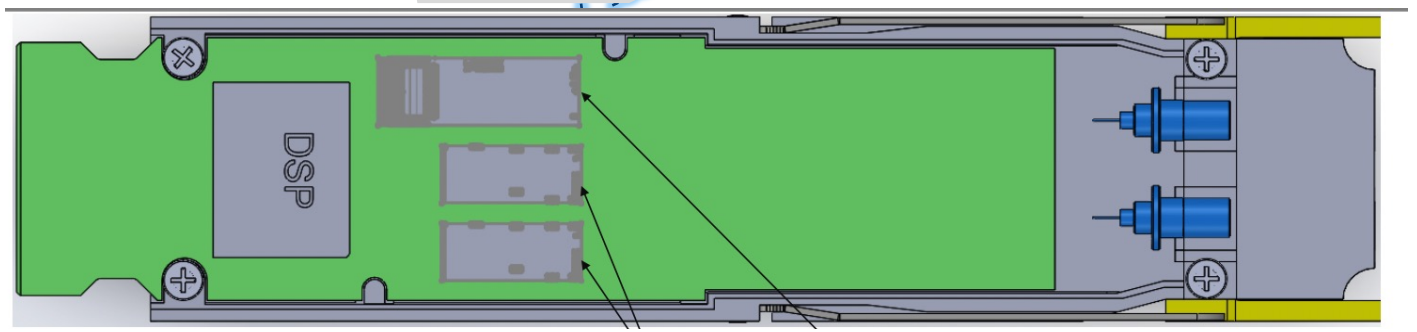
Conventional Discrete Assembly



- **~50 individual pieces; multiple active alignments**
- **Unsustainable for 8 channels ; Impossible for 16**

POET : 75% smaller

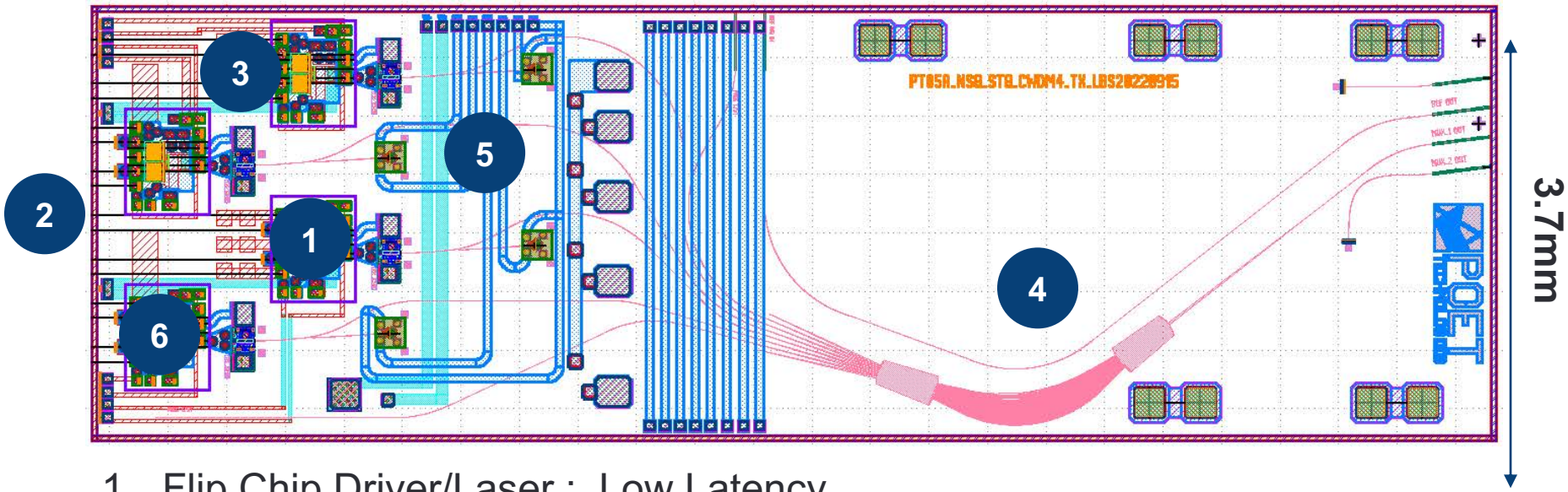
POET's Hybrid Integration



- **2 integrated Tx and Rx optical engines with no active alignment**
- **Readily scalable to 16 channel implementations**

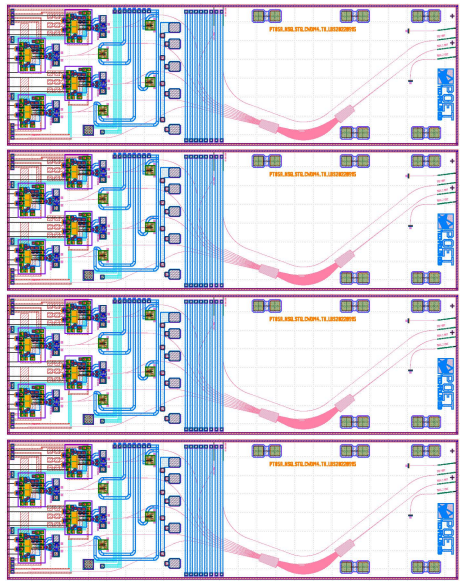
Example of Design Flexibility offered by an Interposer platform

400G CHIPLETS for 1.6Tbps and beyond

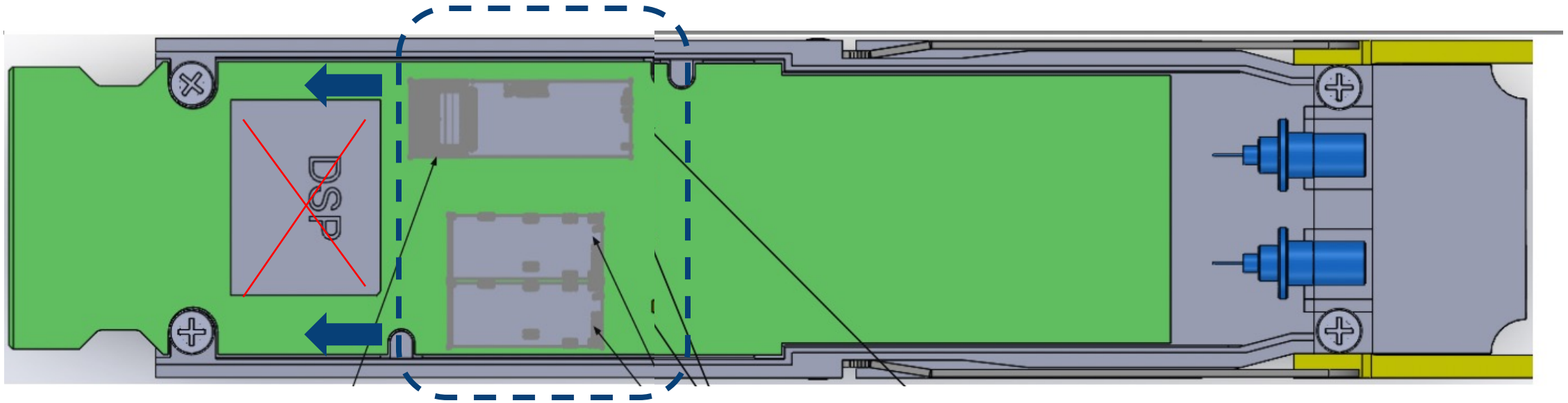


1. Flip Chip Driver/Laser : Low Latency
2. All pads re-configured to a single facet end for each of chiplet integration
3. Through Silicon Vias for Signal Integrity for Signal/Ground
4. Integrated Athermal and Low Loss Multiplexer
5. Integrated Power Monitoring
6. Integrated Passive Devices

Quad Chiplets Integration for 1.6Tbps



Why Scale (and Signal Integrity) matter



- Small Factor / Good Signal Integrity (no wirebonds, direct access to PCB with TSVs) → POET's engines can be located anywhere on the PCB – minimizing the electrical trace lengths
- For 800G and beyond – with no gear box requirements – this can enable Direct Drive capabilities directly from the Switch, eliminating the DSP requirements → 6-8W power reduction per module !!
- Can enable "CPO performance" within a Pluggable Form Factor

Key Competitive Differentiators

POET's Optical Interposer provides a comprehensive integration platform relative to incumbent competing technologies

Competition	Key competitors	Wafer scale Assembly scale and cost	Hybrid integration best of breed components	Form Factor small size & customizable
POET				
Conventional OSA Suppliers	Mitsubishi, Sumitomo, CIG, San-U, Tsuhan, Others			
Silicon Photonics	Intel, Marvell, Cisco, Others			
Vertically Integrated Module Makers	Innolight, II-VI, Others			

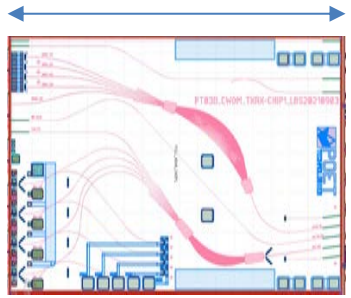
Best in class integration of Tx and Rx: Small size, lower power and customizable design
Compared to other Silicon Photonic PIC vendors

Discrete Component	Vendor A	Vendor B	Vendor C	Vendor D	POET OE
Modulator	✅ Modulator	✅ Modulator	✅ Modulator	✅ Modulator	✅ Modulator
Lasers	✅ Colored lasers		✅ Grey lasers	✅ Colored lasers	✅ Colored lasers
MUX	❓ MUX			✅ MUX	✅ Monolithically integrated MUX
Isolator					✅ None needed
DMUX					✅ Monolithically integrated DMUX
Photodiodes		✅ Photodiodes	✅ Photodiodes		✅ Photodiodes
TIA		✅ Flip-chip TIA			✅ Flip-chip TIA
FAU					✅ FAU

POET's Hybrid Integration Platform provides a COMPLETE solution for next generation Data Center Interconnects as well as other parallel market verticals

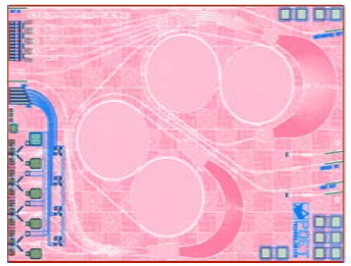
Application Platforms

Directly Modulated Laser Platform



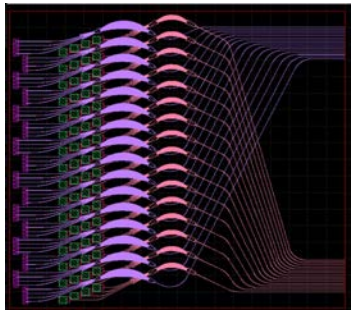
FR4

- 100Gbps
- 200Gbps
- 400Gbps
- 800Gbps



LR4

- 100Gbps
- Custom Configurations with multiple engines form factors

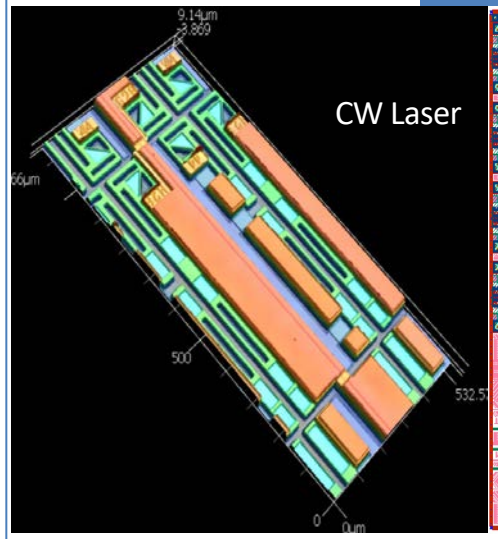


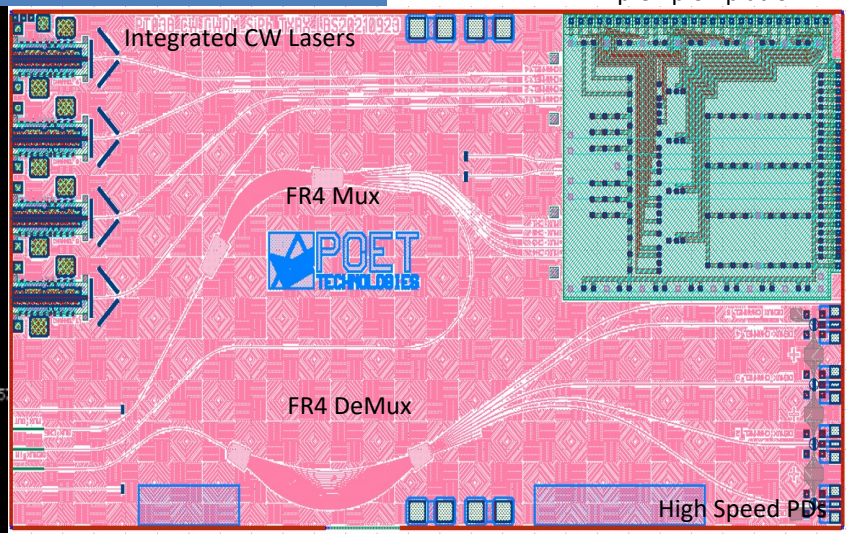
6.4Tbps

- DML/EML Implementation
- Custom Configurations
- Industry leading form factor with two layer waveguides (optical chiplet : 18mmx18mm)

CW Laser Platform

External Modulator Flip Chip on platform





800Gbps (2x400FR4) and beyond

- Platform with CW lasers compatible with external modulators like Si Photonics
- Extensible to 200G/λ with TFL (thin film LiNbO3) modulators

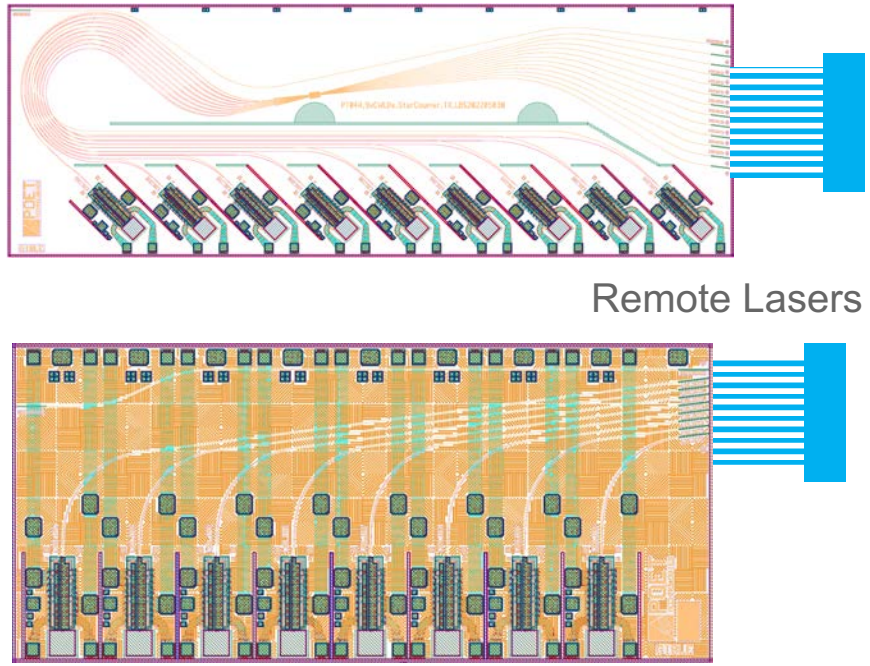
Remote Light Sources

- C Band and O Band Applications
- CPO and AI applications

Optical Interposer Light Sources for High Bandwidth Communications

- Engaged with leading AI-ML Accelerator and Chip-Chip communication companies to provide novel light sources at lower cost and greater flexibility than conventional laser suppliers.

POET Solutions



- POET's Optical Interposer platform enables wafer scale, passive assembly of **high channel count lasers – with in-built splitting / multiplexed solutions as required**
- **Eliminates the requirements** for laser array use which are very expensive
- **Meets cost, form factor and SCALE requirements** for high volume applications
- **Optimized laser coupling efficiency** and power
- **Ability to integrate micro-optics** at wafer scale
- Chip-on-board construction ; **Eliminate expensive PM cables otherwise required**

III Optical Interposers for Integrating New Materials

Monolithic Integration
Deposited or Grown on the wafer

- Best Cost Option Potential
- Complex Performance tradeoffs
- Limited Materials Choice
- Mature for some platform materials (eg. SiN)

Hybrid Integration
Assembled on to target as finished components

- High Flexibility
- Wafer Scale Assembly Techniques with pick and place
- Known Good Die
- Great option for limited numbers of components
- Limited Performance Tradeoffs
- Packaging Simplicity
- Best components for the application

Heterogenous Integration
Transferred / Bonded on the wafer

- High Material Integration flexibility
- Best Material for the application
- Low Cost Potential
- Emerging Technology

Lithium Niobate has advantages but lacks Integration Capability

More Bandwidth
(internet bandwidth grows by 100X in the next decade)

More compact and faster EO Modulators

EO Light control below 1um wavelength
(In wavelength range that Silicon or InP are not transparent)

Wide Transparency Window

Integration and Scalability
(The magic of the Interposer is the miniaturization of optics)

Extend Capability without giving up integration and scalability using a Heterogenous Interposer

Power Consumption
(Data Centers consume increasingly large percent of energy)

Efficient and Low Loss EO Modulators

Non Linear Photonics and Metrology
(Wavelength conversion, 2nd harmonic generation, optical frequency combs)

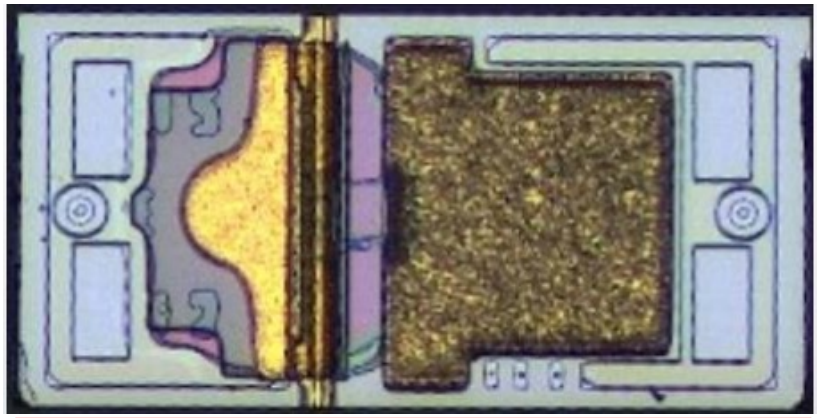
Large $\chi^{(2)}$ and $\chi^{(3)}$ Optical Non Linearity

An **Optical Interposer** breathes integration potential to novel materials which otherwise might have challenges integrating to the tight form factors required for next generation modules

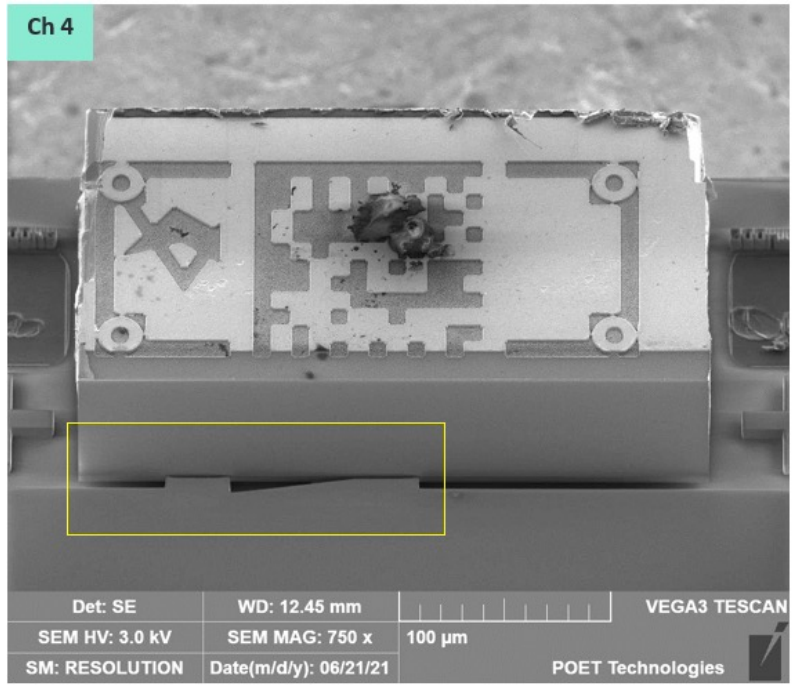
Topics

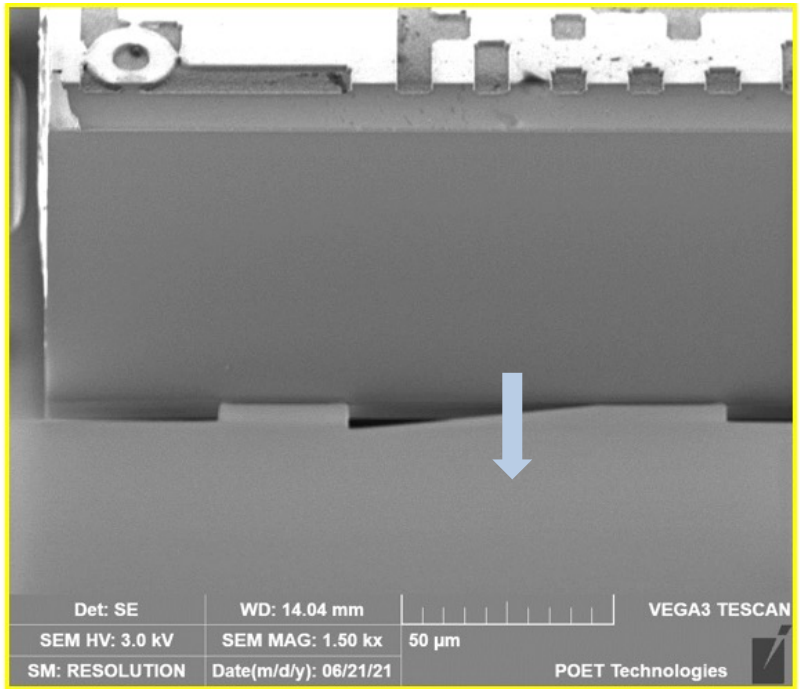
- Introduction
- Application Proof Points
- Conclusions

Flip Chip Lasers Integration in POET's Optical Engines

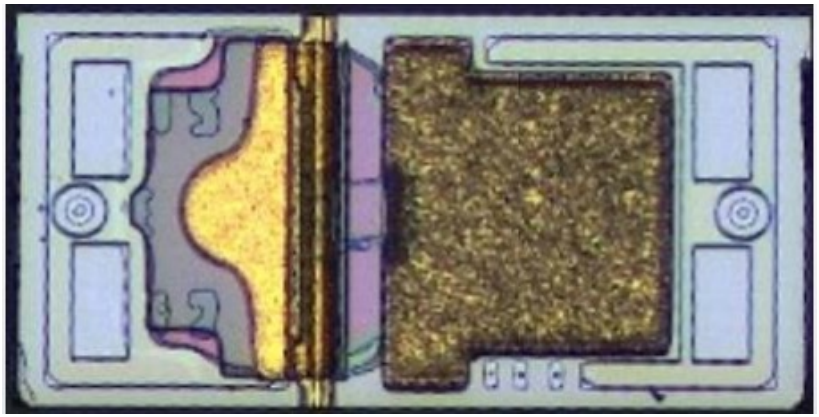


- POET's Interposer platform includes proprietary features for laser attach
- Laser – waveguide coupling performance excellent for both CW and DML lasers
- Passive laser placement and wafer scale assembly



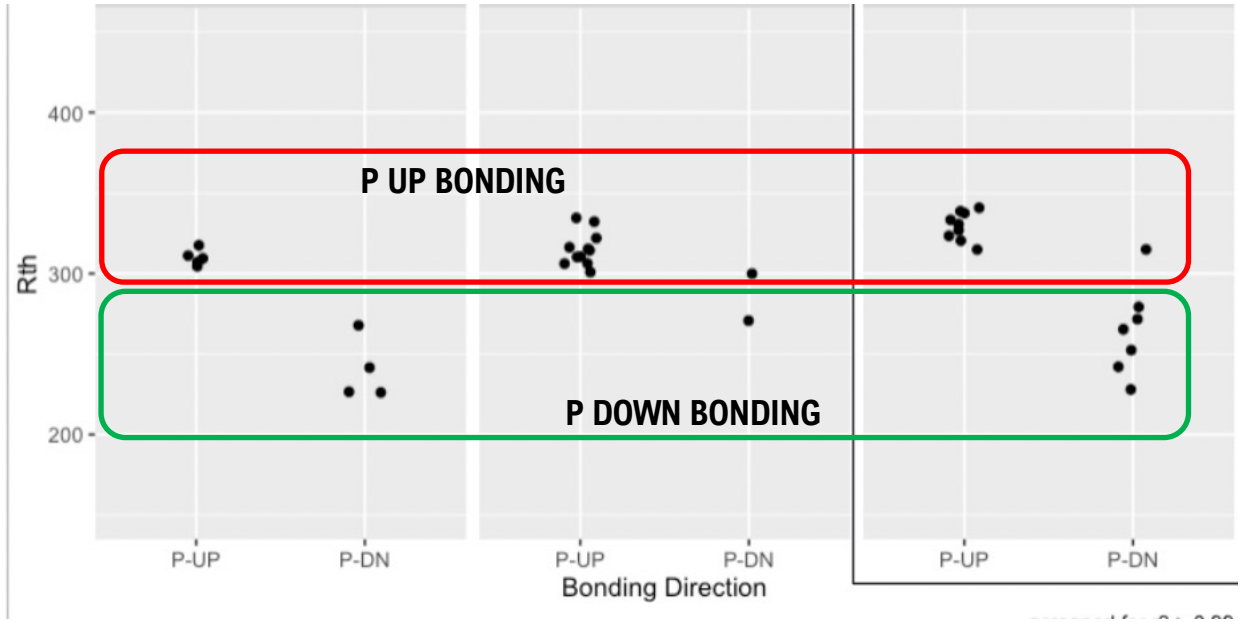


Thermal Resistance



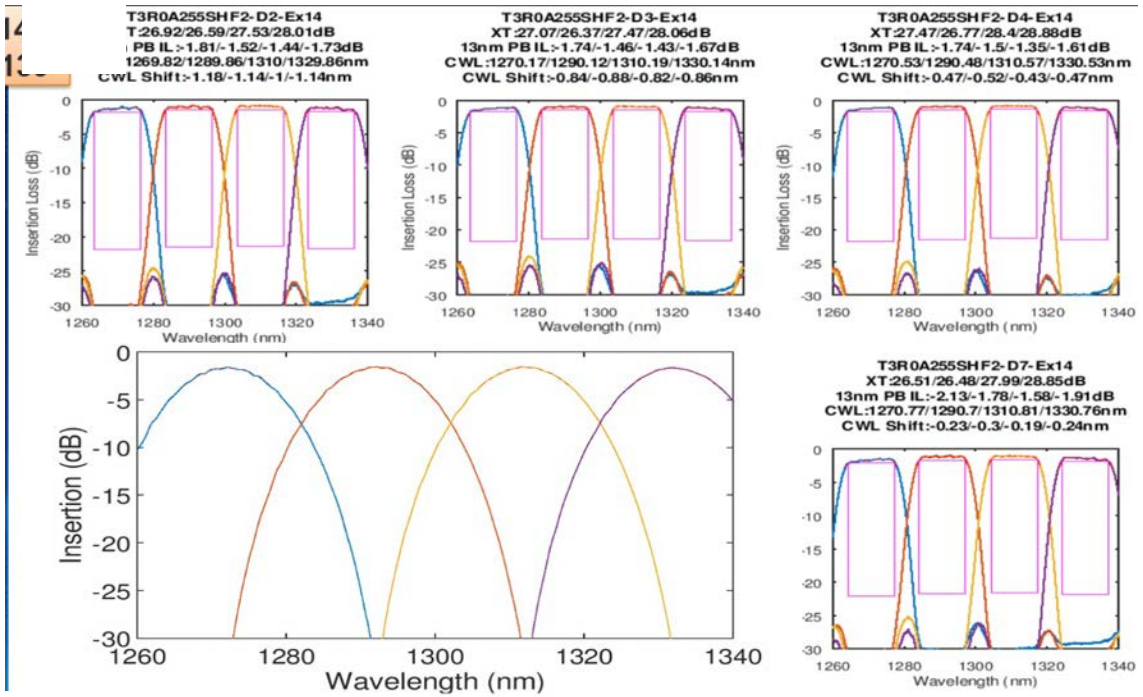
- The Thermal Resistance of the Interposer dictates the high temperature performance of the laser which in turn affects such parameters as Reliability, Bandwidth and Power consumption
- Optimization of the assembly conditions helps achieve equivalent thermal resistance for ultra small DML lasers that are only **250um x 150um** in size

Good Laser thermal performance demonstrated for latest generation of 56G DML lasers

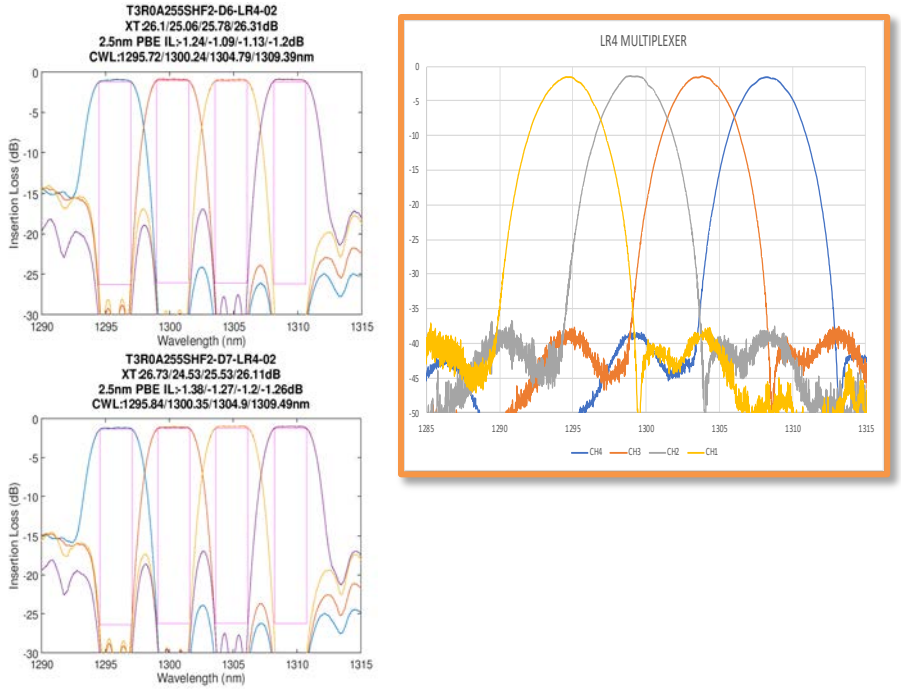


FR4 (100G/200G/400G) and LR4(100G) Filter performance

FR4 : 13nm pass band, 20nm channel spacing



LR4 : 2.5nm pass band, 800GHz spacing



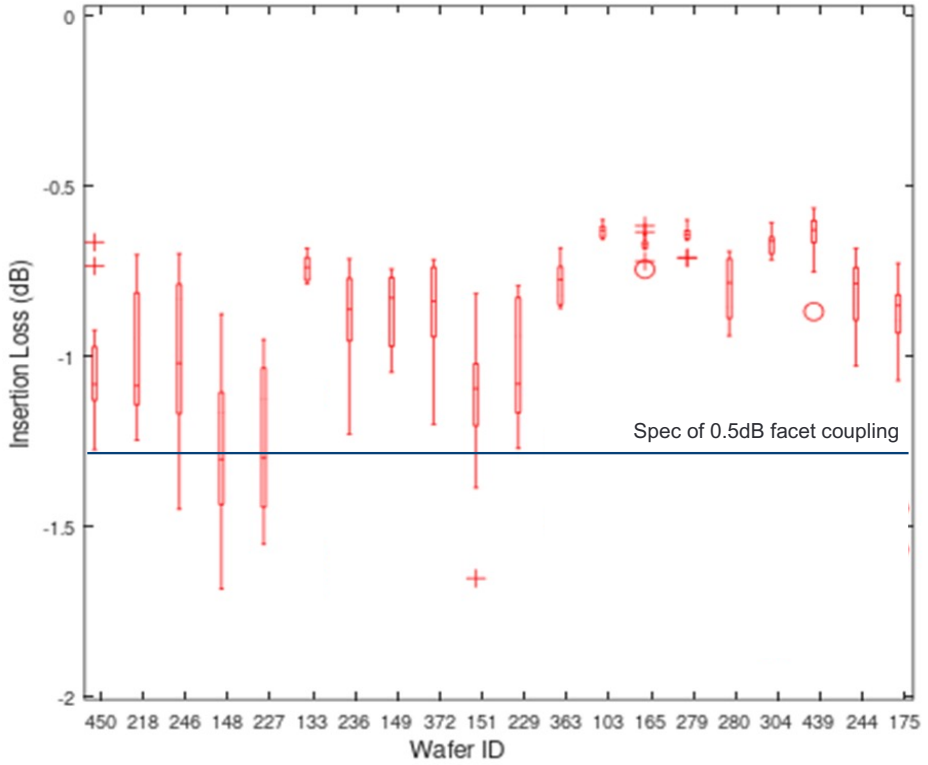
- Insertion Loss including fiber coupling < 1.8dB (FR4) and < 1.5dB (LR4) including fiber coupling
- Cross Talk > 25dB
- Design frozen and taped out for qualification and production
- Data accumulated on 100’s of chips across multiple wafers

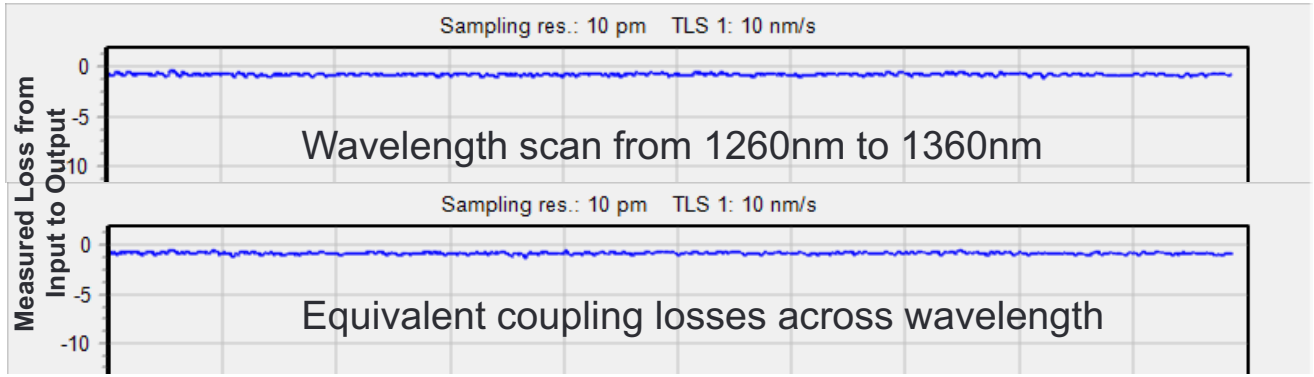
Industry Leading Fiber Coupling Performance

- Measured Fiber Coupling Optical Losses

Total loss from input to output : 0.7dB
Best measured fiber coupling loss : 0.2dB/facet

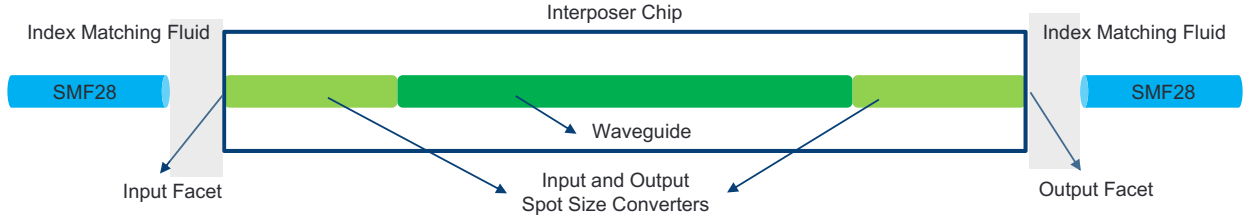
Transmission Loss : 0.3dB
Expected in Production: 0.5bB/facet





Measurement Set Up

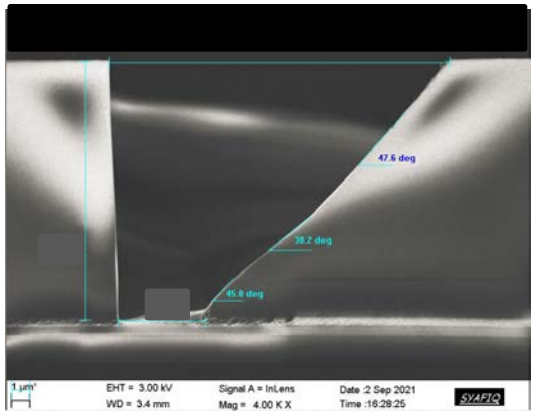
Total Measured Loss = 2 x Facet Coupling + Transmission

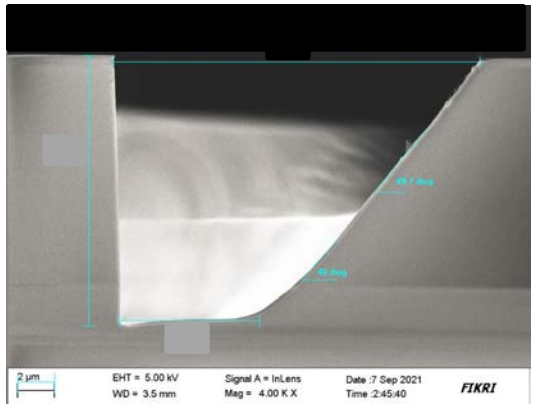


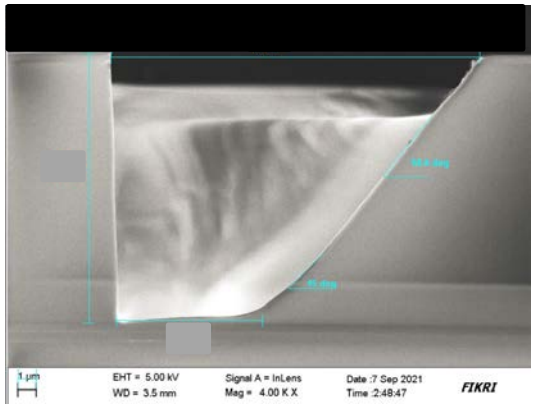
Vertical Coupling Mirrors

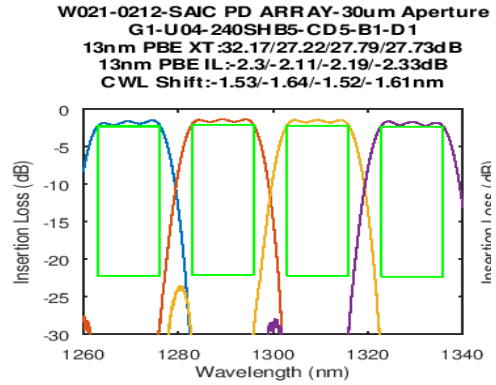
POET uses vertical coupling mirrors as a low loss alternative to grating couplers to couple light “out of plane” to the waveguides – these are used for coupling light to conventional top entry / emitting devices and for wafer level test

Linear Mirrors : Used with 100G/200G PDs (28Gbps)

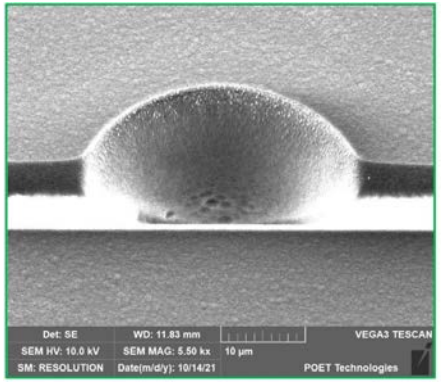


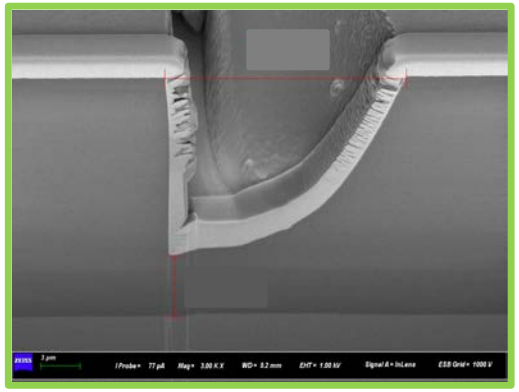


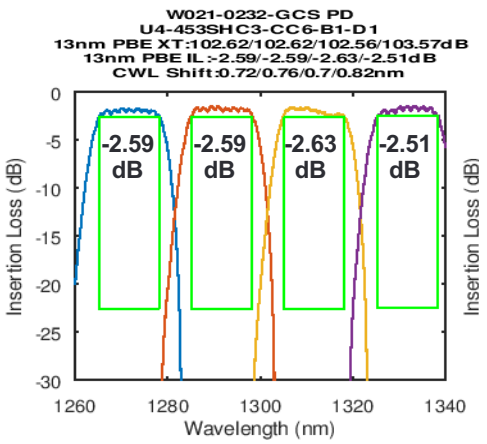


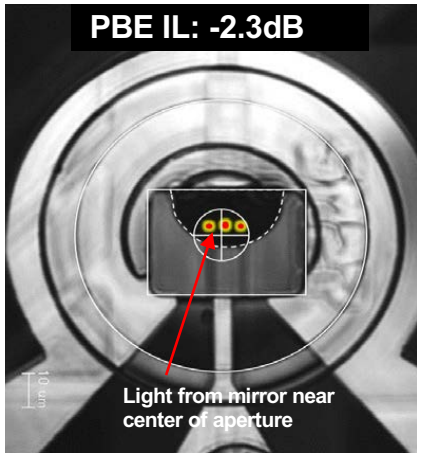


Paraboloid Mirrors : Used with 400G PDs (56Gbps)

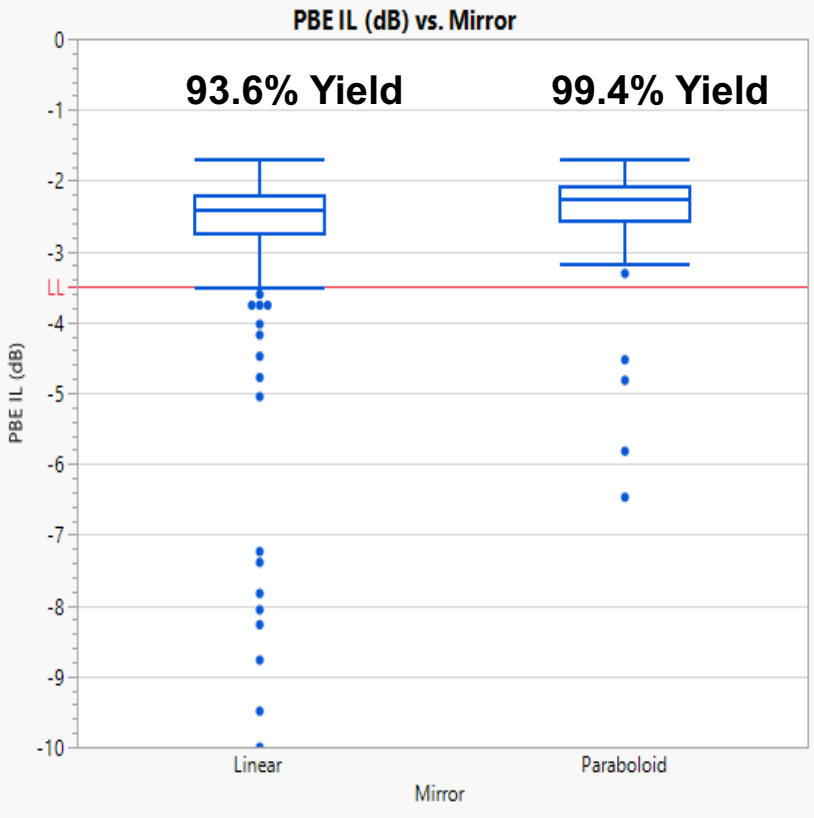


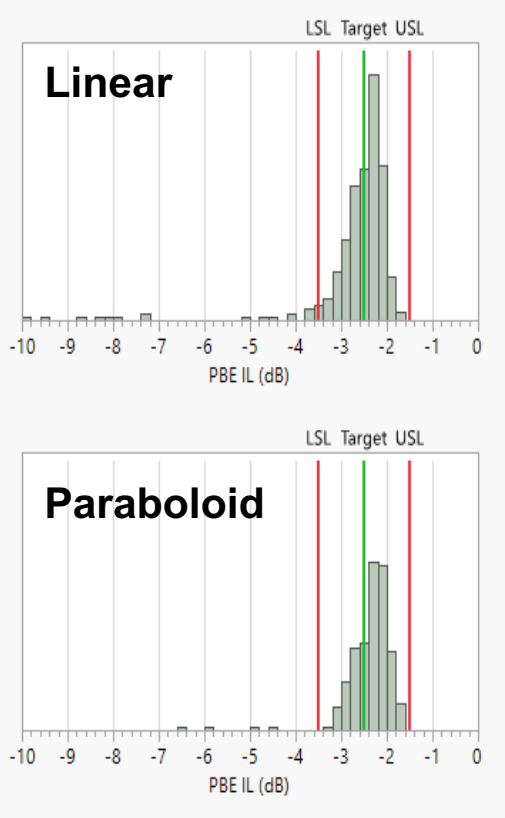


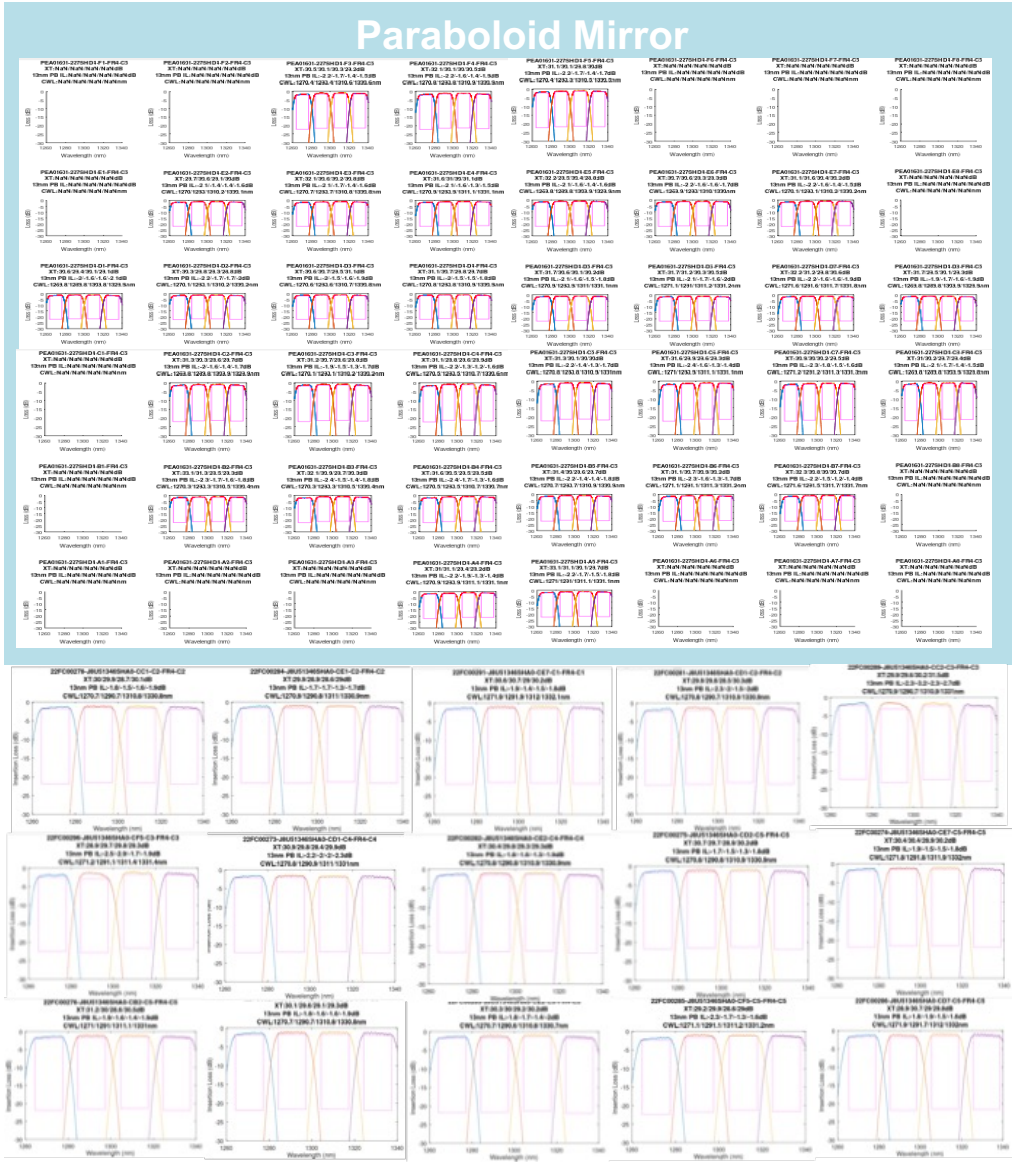




Vertical Mirror Performance







Consistent performance both pre and post PD bonding

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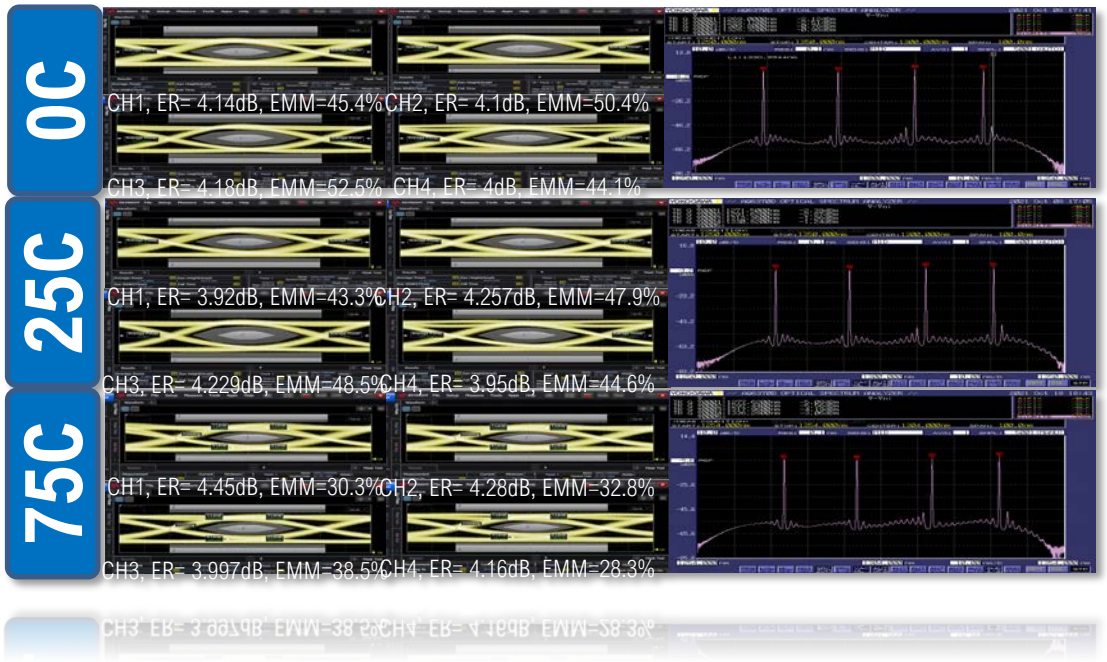
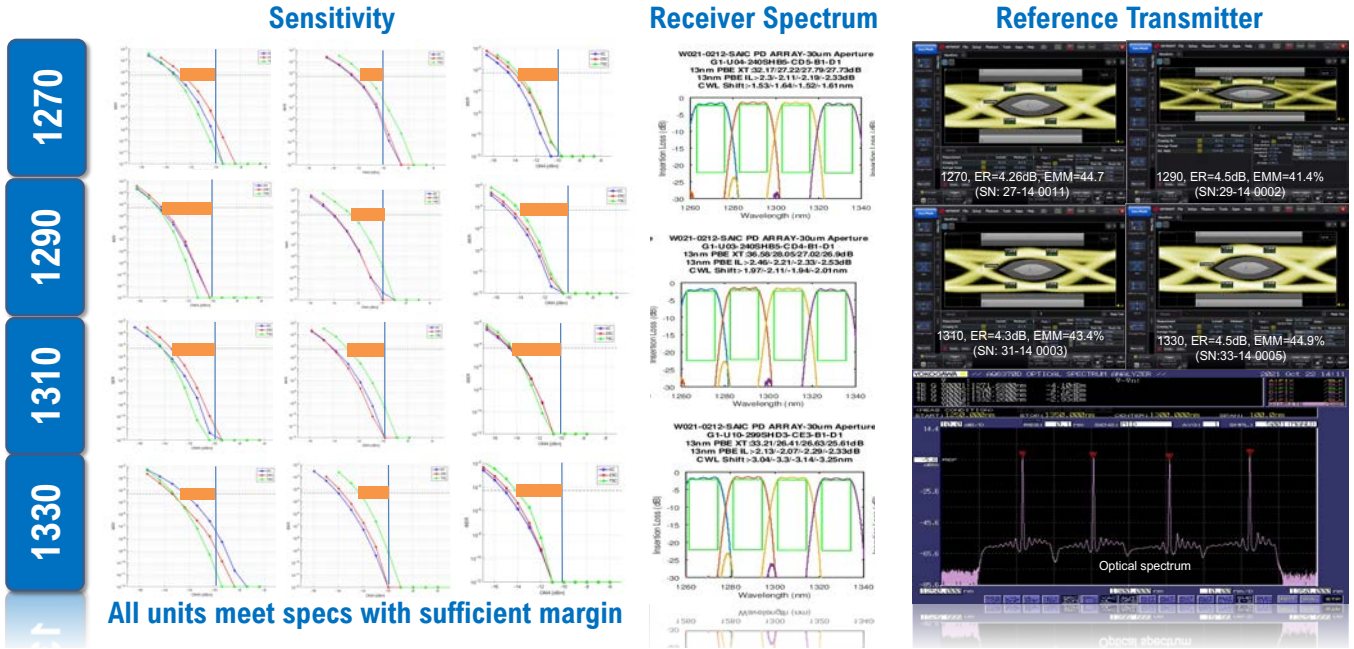
100G CWDM Optical Engine

TRANSMITTER



RECEIVER

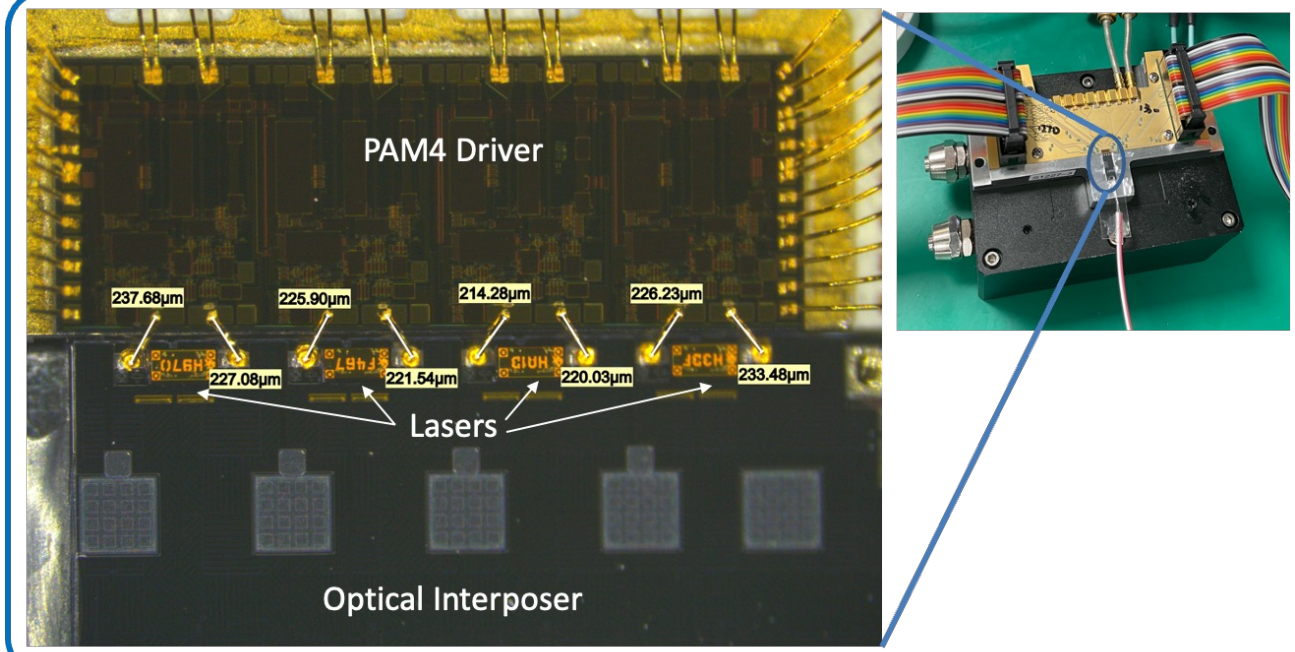


- Excellent Eye Margin and Extinction ration across the temperature range for Data Centers
- DML engine is extensible in performance from 100G -> 200G – 400G
- POET will offer the lowest cost, highest density DML engine by incorporating 56Gbaud DMLs into its platform
- Competitive solution for Co-packaged optics

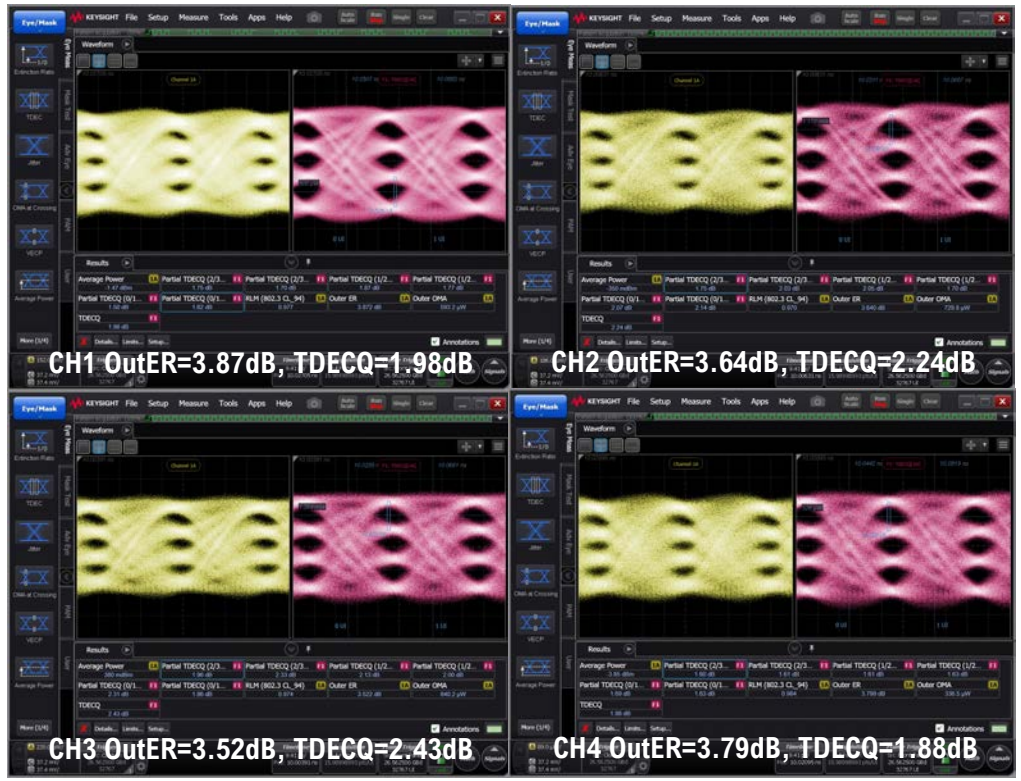
200G FR4 Optical Engine

Common Optical Engine meeting the requirements of 100/200G

200G Optical Engine on Evaluation Board

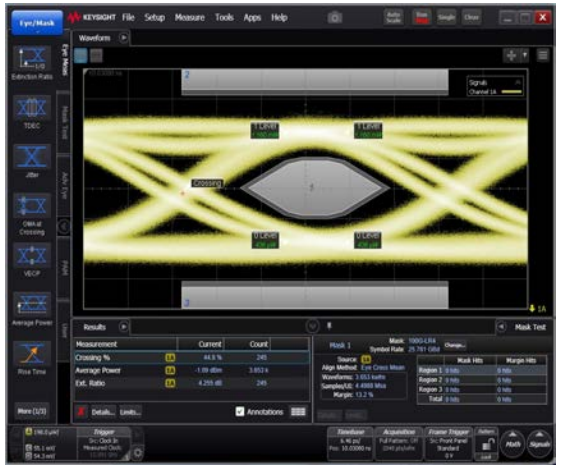


Optical Performance @ 75C



Excellent 200G PAM4 signals through the Optical Interposer
200G Rx also shows excellent performance (not shown)

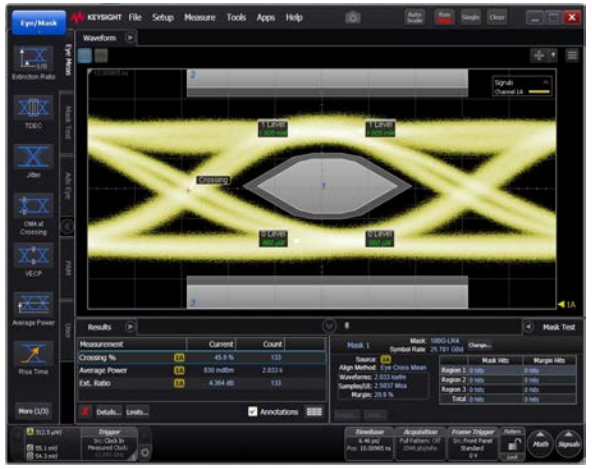
100G LR4 Optical Engine



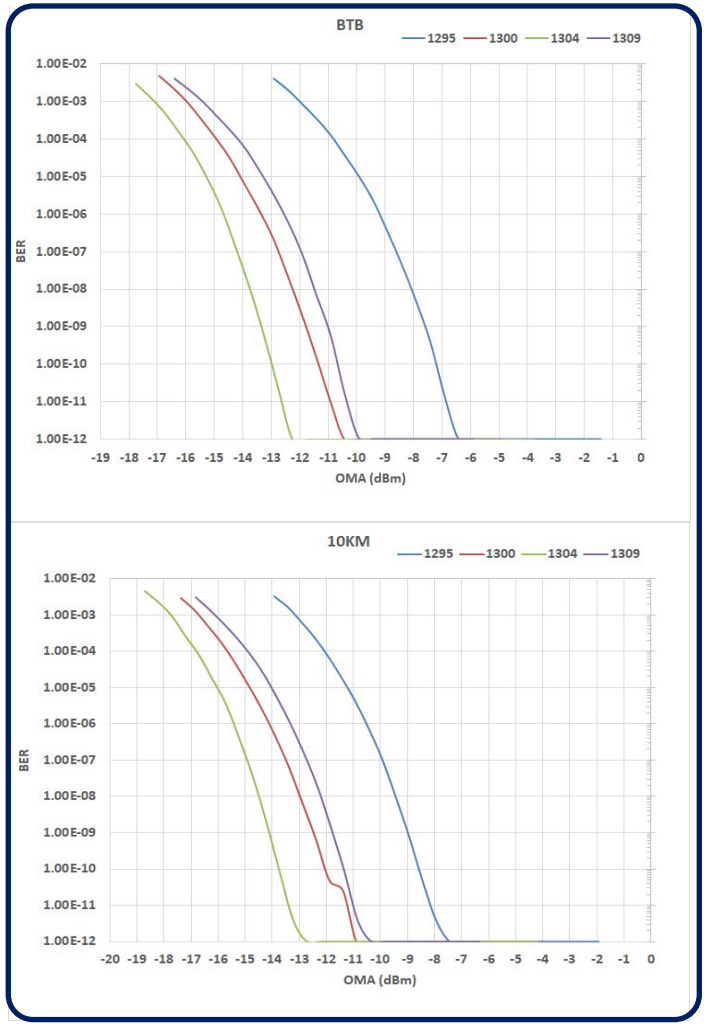
CH1 ER=4.25dB, EMM=13.2%

CH2 ER=4.4dB, EMM=15.4%

CH3 ER=4.23dB, EMM=21.4%



CH4 ER=4.36dB, EMM=20.9%

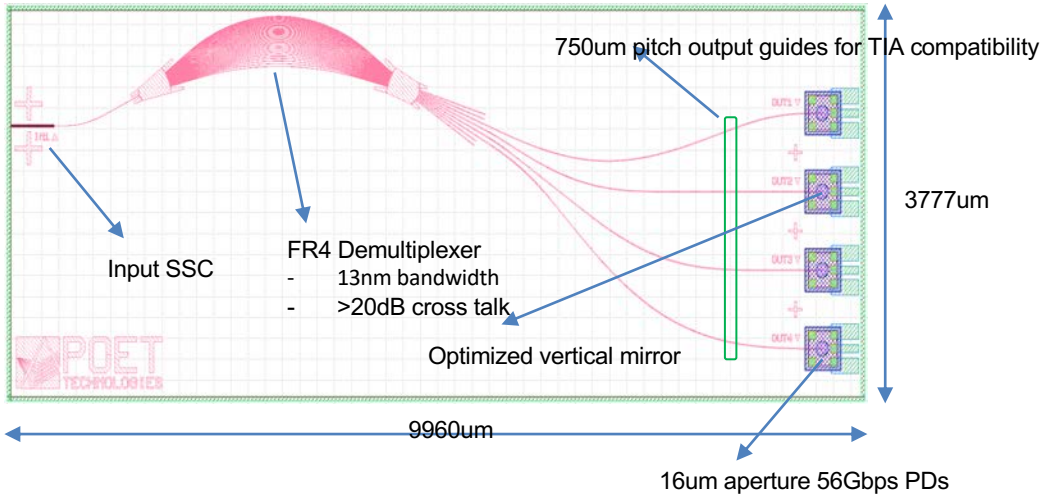


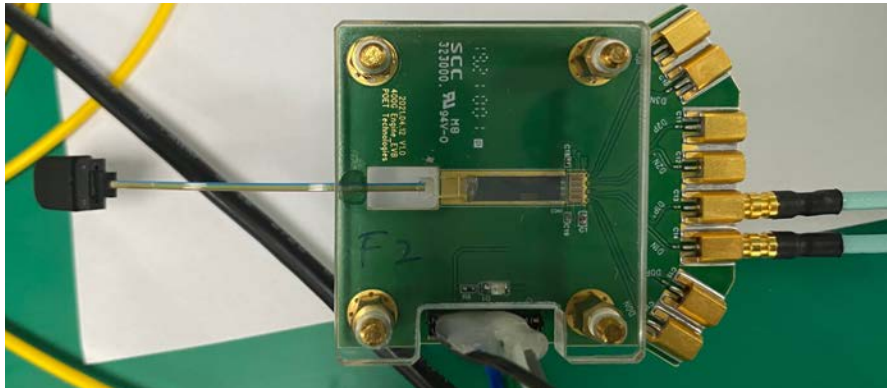
Channel 1 performance impacted by OOS wavelength

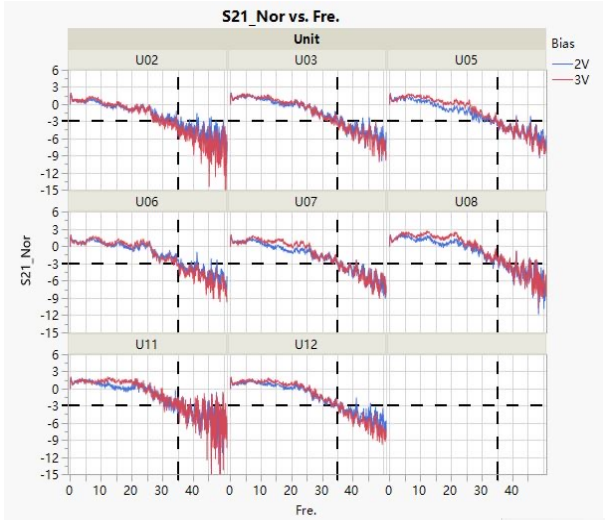
Industry first implementation of a “chip on board” LR4 implementation !!

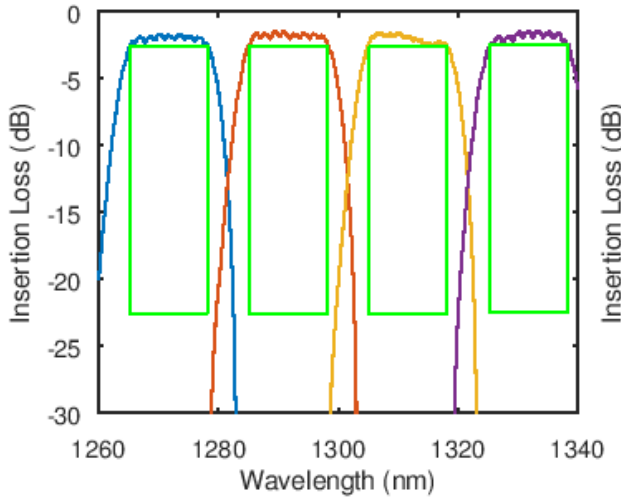
400G/800G FR4 Receiver Performance

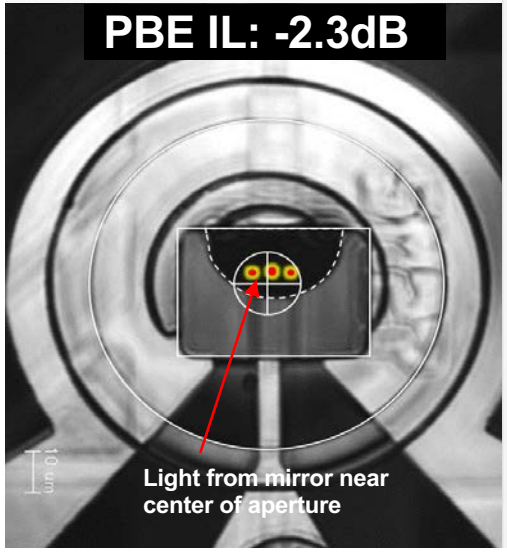
400G FR4 Receivers integrated into 400G FR4 engine

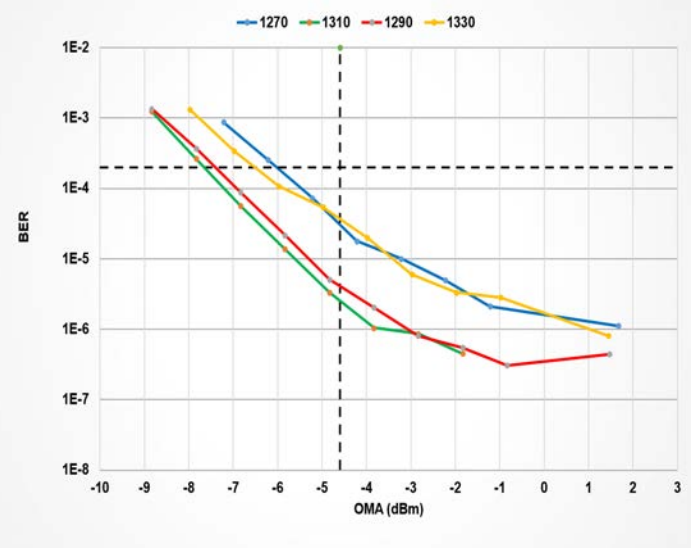




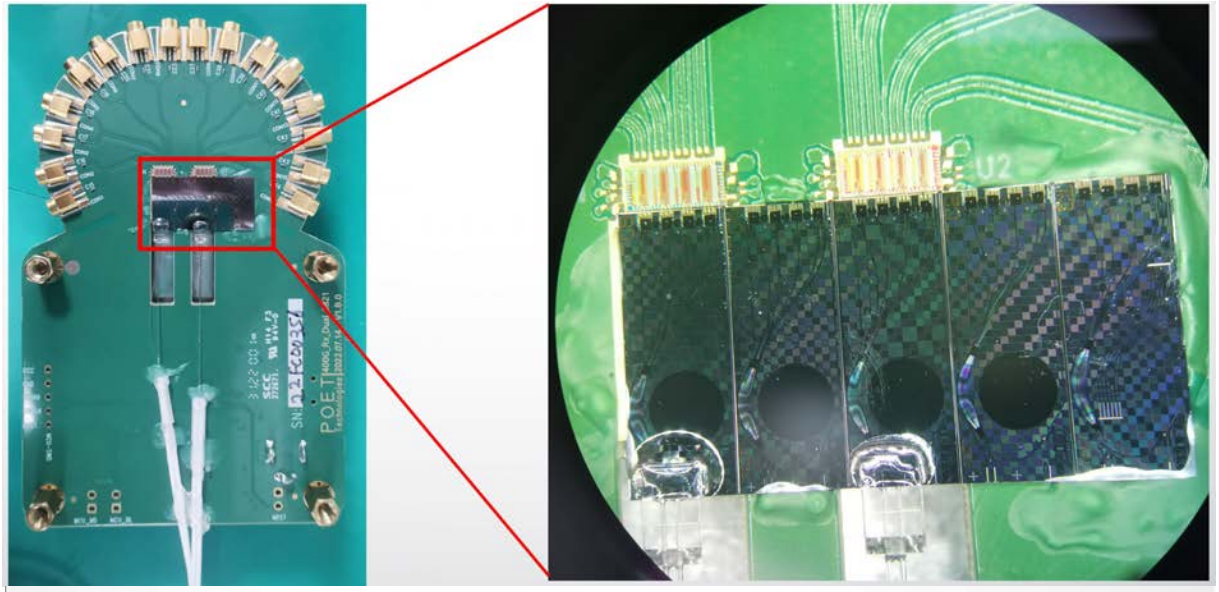


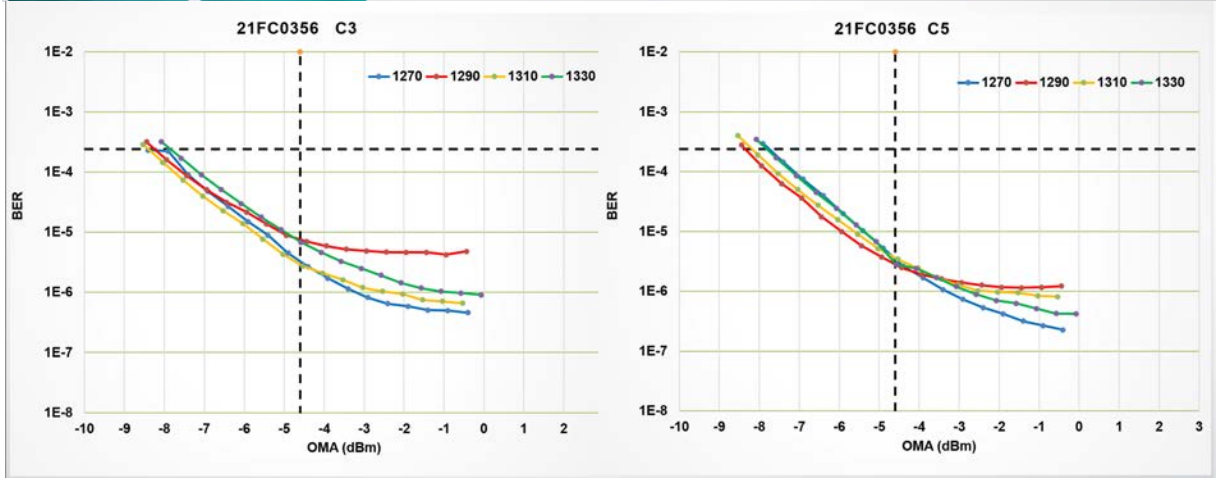


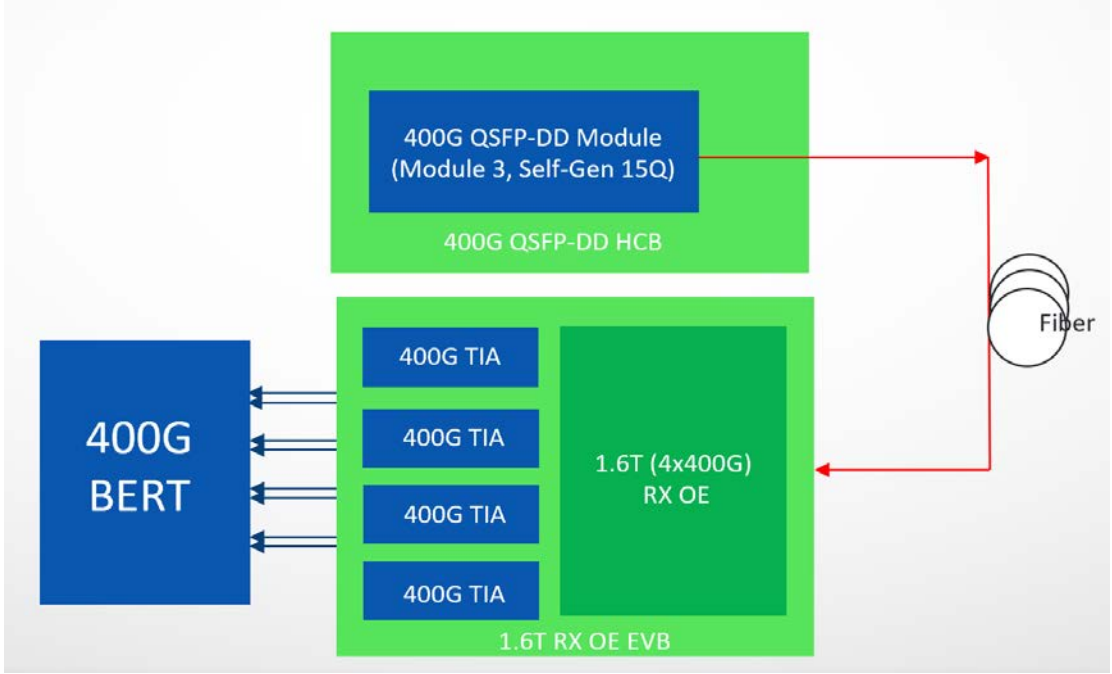




1.6Tbps FR4 Demonstrator



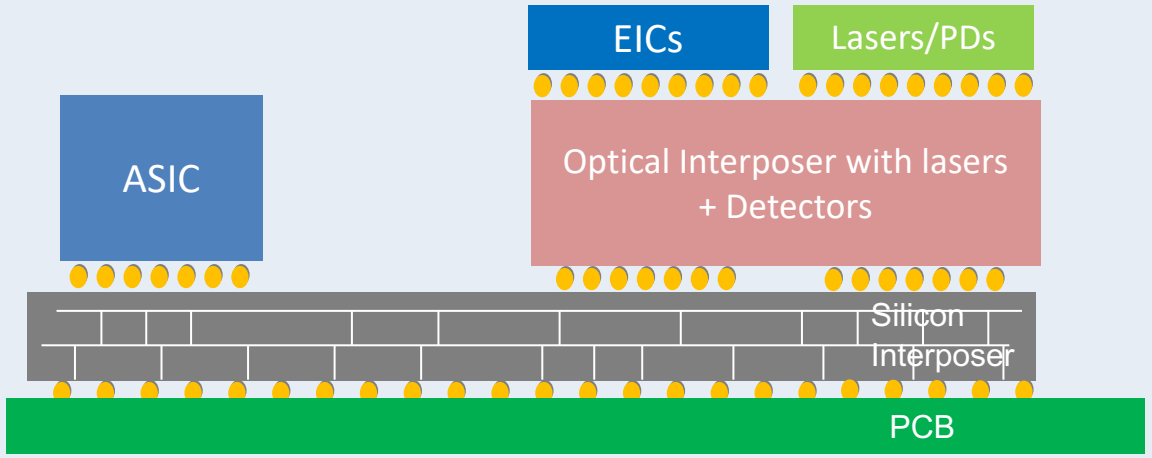




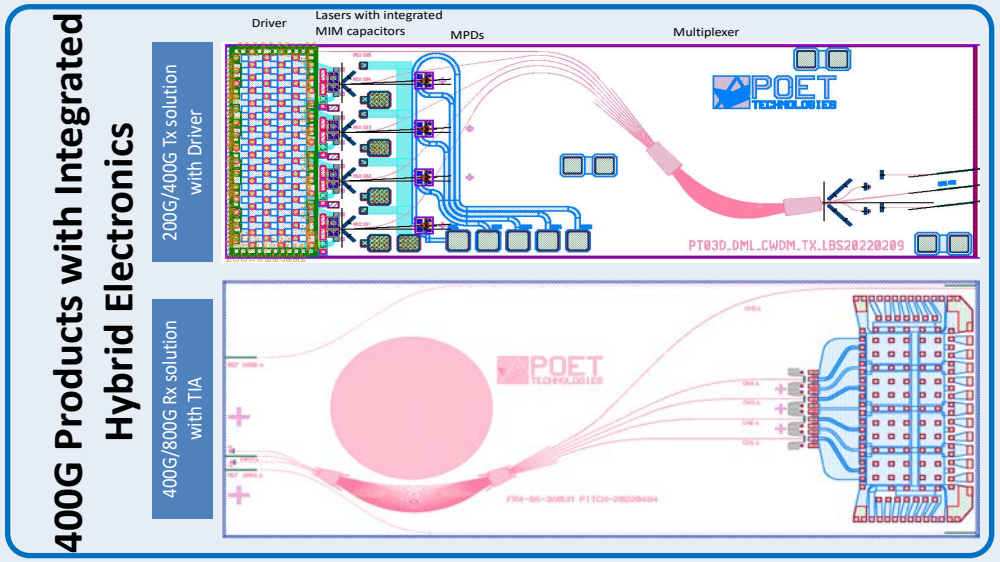
Topics

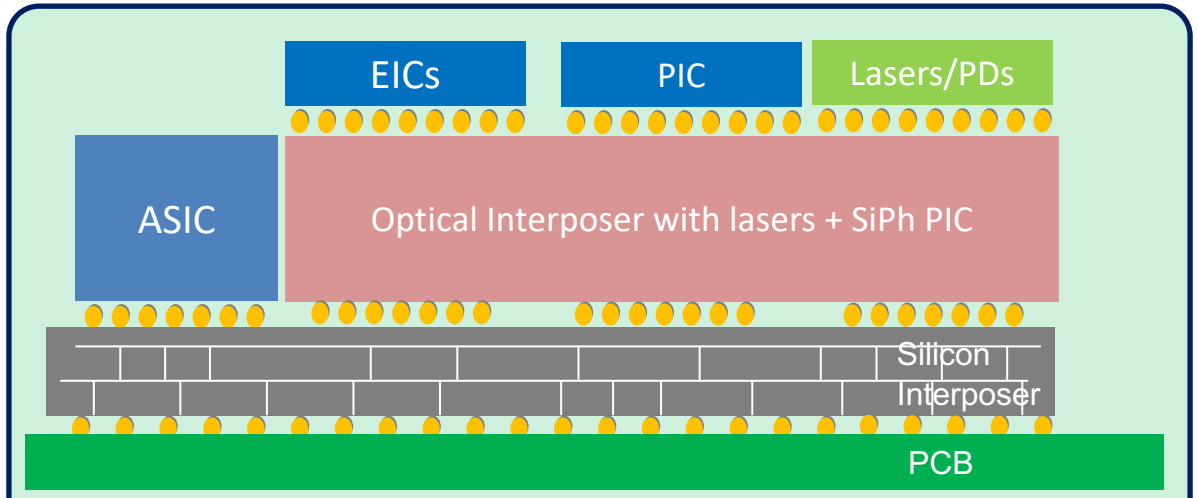
- Introduction
- Application Proof Points
- Conclusions

Flexible Architectures for multiple applications

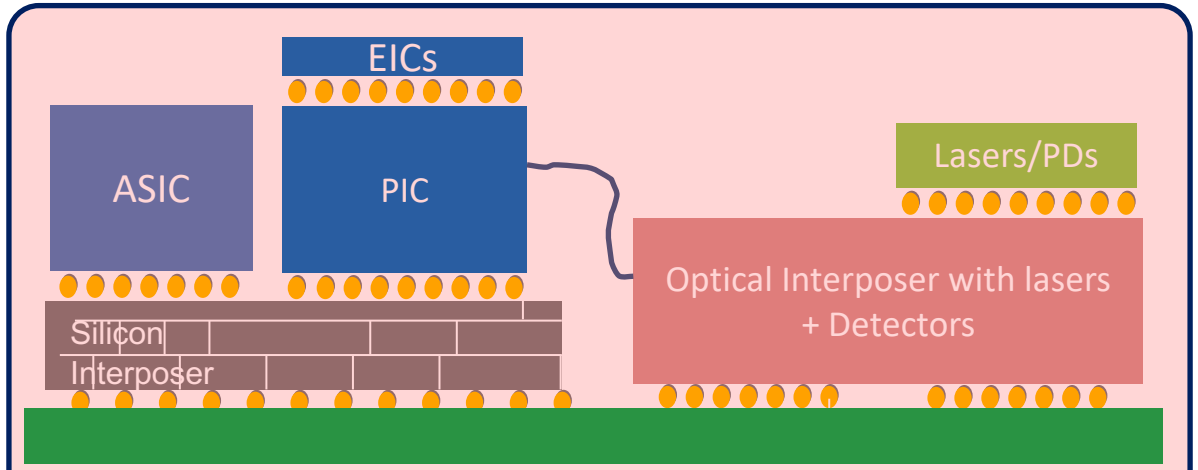


Modulated Laser solutions using the Optical Interposer





Integrated Laser/PIC solution using the Optical Interposer



External Laser solutions using the Optical Interposer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