LN-on-Insulator Modulator Technology for B400G Ethernet Application

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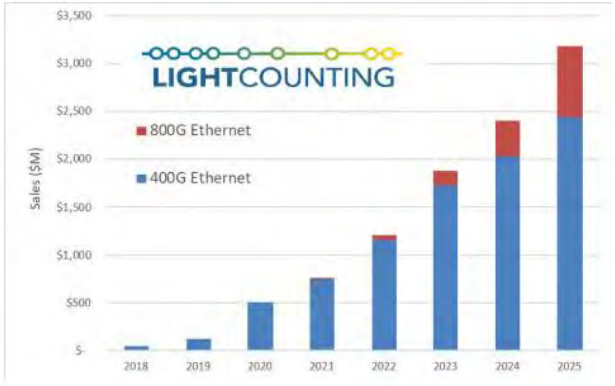
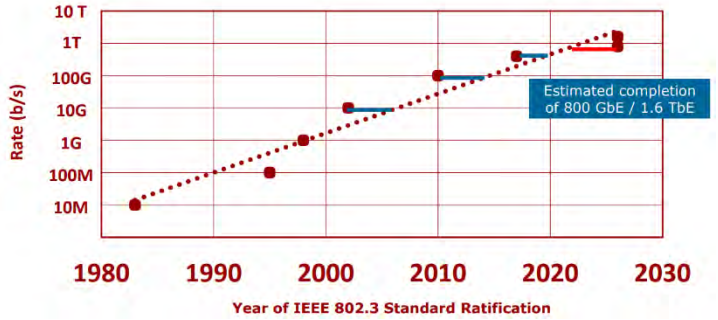
Recap: B400GE Application

In Vlad Kozlov's contribution kozlov_b400g_01_210211, market projection was reviewed. B400GE, starting with 800GE, will start to pick up in 2022 and later.



In the Chair's report in March, dambrosia_b400g_01_210301, the below timeline projection of B400GE standard development was discussed.



Summarized in the Chair's report in April, dambrosia_b400g_02_210426, the group has adopted the below objectives of physical layer specification

- Adopted by B400G SG, Apr 2021
- Approval by 802.3 WG Pending

- Support a MAC data rate of 800 Gb/s
- Support full-duplex operation only
- Preserve the Ethernet frame format utilizing the Ethernet MAC
- Preserve minimum and maximum FrameSize of current IEEE 802.3 standard
- Define a physical layer specification that supports 800 Gb/s operation over 8 pairs of MMF with lengths up to at least 50 m
- Define a physical layer specification that supports 800 Gb/s operation over 8 pairs of MMF with lengths up to at least 100 m
- Define a physical layer specification that supports 800 Gb/s operation over 8 pairs of SMF with lengths up to at least 500 m
- Define a physical layer specification that supports 800 Gb/s operation over 4 pairs of SMF with lengths up to at least 500 m
- Define a physical layer specification that supports 800 Gb/s operation over 4 pairs of SMF with lengths up to at least 2 km
- Define a physical layer specification that supports 800 Gb/s operation over 4 wavelengths over a single SMF in each direction with lengths up to at least 2 km
- Define a physical layer specification that supports 800 Gb/s operation over a single SMF in each direction with lengths up to at least 10 km
- Define a physical layer specification that supports 800 Gb/s operation over a single SMF in each direction with lengths up to at least 40 km

- 100Gbps per optical lane at DR (current optical PMDs defined by cu)
- 200Gbps per optical lane at DR/FR, maybe LR
- 800Gbps coherent is a potential candidate for LR and ER

- Technical feasibility of B400GE in terms of signaling, BER, FEC are being actively discussed.
- This contribution discusses a possible technology for the new optical PMDs at higher data rates.

Do/Will we have a good selection of modulator technologies for B400GE Application?

Technical variety is helpful for building a healthy ecosystem and continuously driving down the cost.

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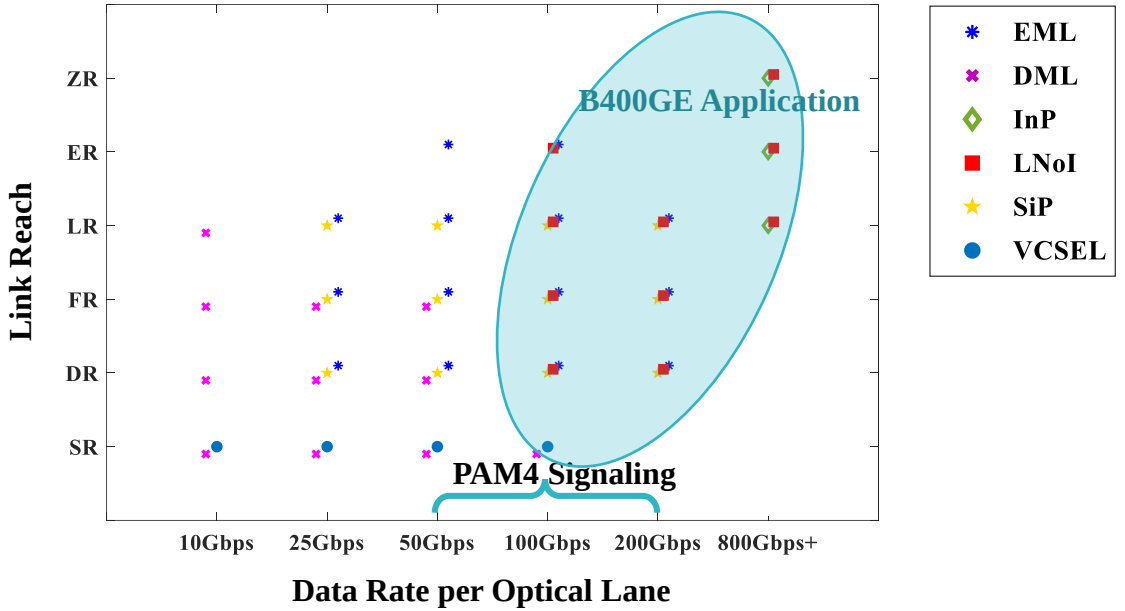
Choices of Modulator Technologies for Ethernet Application



- Reported LNoI MZM modulator can easily reach and above 60GHz EO bandwidth, along with good linearity, and low insertion loss
  - Leaves room to move around and compromise among other components used in the link
- One technology serves for the two use cases of B400GE, both IM-DD and coherent
  - Less investment in fabrication
  - Bring down the Cost/chip by mass production
  - Brings benefits of cost down approach
- Typical Bandwidth of SiP MZM modulators <40GHz, requires stronger pre-emphasics/EQ/CTLE/FEC to work at 200Gbps/lane, that means higher power, longer latency

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LNoI modulator is a new but *old* technology

- Commerical LN modulator companies launching LNTF technologies
  - V. Stenger, A. Pollick, and C. Acampado, "Integrable Thin Film Lithium Niobate (TFLN™) on Silicon Electro-optic Modulators," in Optical Fiber Communication Conference (OFC) 2019, OSA Technical Digest (Optical Society of America, 2019), paper Tu2H.6.
- Mass production of LNoI Wafer @ 6'' now, and moving to 8''
- Industries investing on pre-Research and R&D of LNoI
- Key technology IP holders founding startups
  - Some have secured VC investment
- Foundry is not overlooking the potential of LNoI
  - Reza Safian, Min Teng, Leimeng Zhuang, and Swapnajit Chakravarty, "Foundry-compatible thin film lithium niobate modulator with RF electrodes buried inside the silicon oxide layer of the SOI wafer," Opt. Express 28, 25843-25857 (2020)
- Reuse of most current eco system and PDA flow of current photonic technologies, i.e., SiP and InP
  - Very well known physical and electromagnetic theory
  - Same design flow and simulation software
  - Same fabrication process flow and major instrument
  - Same packaging process as SiP

Therefore, it is not too optimistic to predict LNoI technology can be commercially ready in time with the vast deployment of 200G-PAM4 and B400G coherent modules. It then provides a strong candidate as a cost effective component for B400GE application.

Homogeneous LNoI modulator

Homogeneous Approach

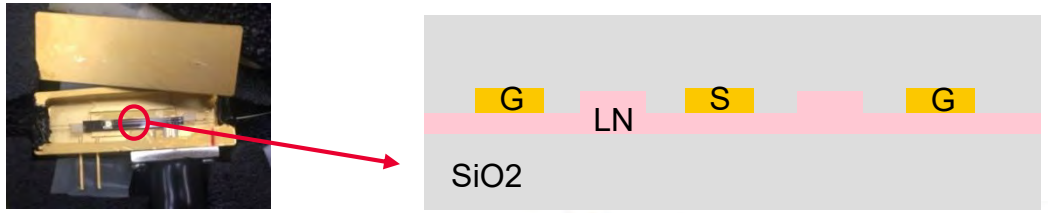
The modulator device comprises of LNoI

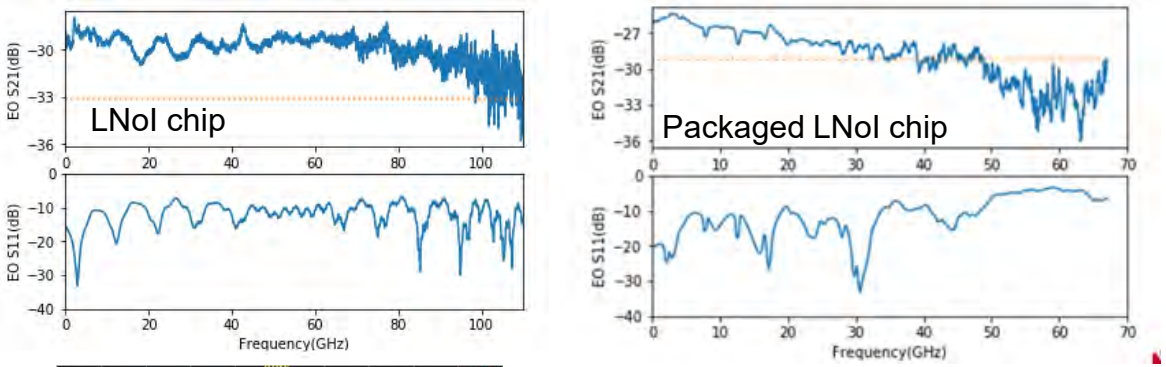
- Coupling Loss to SMF<0.6dB, Modulator loss~2.5dB
- 3-dB EO bandwidth >100GHz
- With its low loss, high bandwidth and good linearity, it is possible to reach for 200GPAM4 10km application
- Very low loss EO phase shifter allows high modulation efficiency, <1.1V driving voltage achievable
- ODSP direct drive application
- Reuse of CMOS/SiP fabrication facility

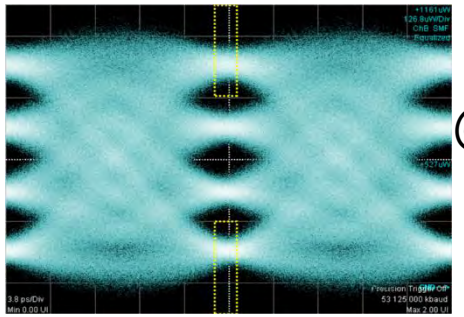
Components are being optimized for practical product

Further reading on the LNoI modulator technology –homogeneous approach can be found in

Wang, C., Zhang, M., Chen, X. *et al.* Integrated lithium niobate electro-optic modulators operating at CMOS-compatible voltages. *Nature* **562,** 101–104 (2018). https://doi.org/10.1038/s41586-018-0551-y
Yuan, S., Hu, C., Pan, An.et al. Photonic devices based on thin-film lithium niobated on insulator. 2021 J. Semicond. **42** 041304. https://iopscience.iop.org/article/10.1088/1674-4926/42/4/041304/meta







@1.44Vpp

112G PAM4 ER 5.18 TDECQ2.59

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The shown results are the outcome of preliminary laboratory work, and do not represent the best optimized . This presentation is to show technical feasibility of LNoI in B400GE application, and should not be interpreted as indication of product performance or technological preference of Huawei.

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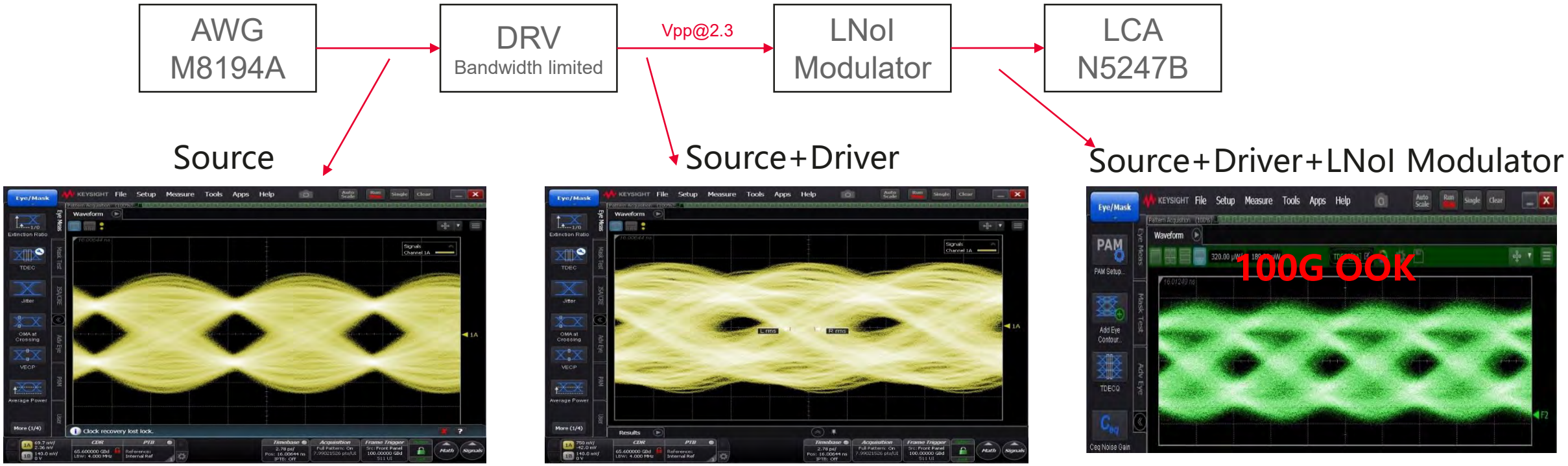
Homogeneous LNoI modulator

- Limited by the testing instrument , we were only able to test the modulator against 100G OOK signal at the time, but from the S21 response and 100G-OOK eye diagram, the modulator could work for 200G-PAM4 signaling.
- Improvement on packaging and test apparatus is in progress and 200G-PAM4 testing will be involved in future work.



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Hybrid Si/SiN/LNoI modulator

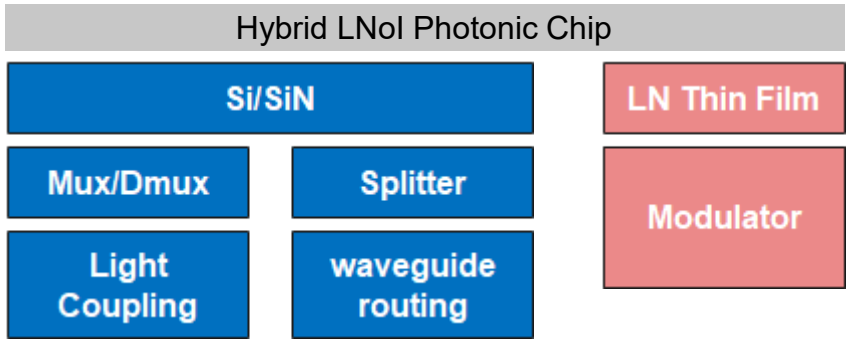
Hybrid Integration Approach

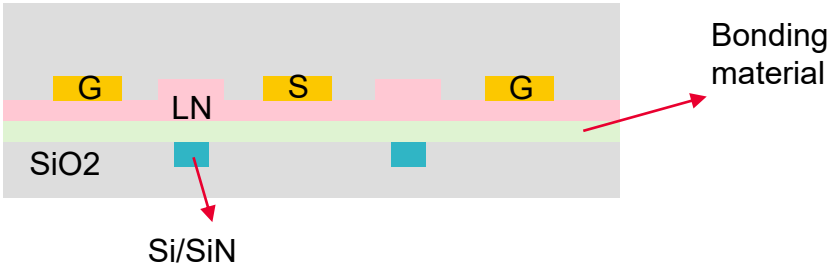
Integration with Silicon/SiN

- Optical Mode transfers from Si/SiN waveguide to LN waveguide where modulation happens
  - A coherent modulator was reported working with up to 80GBd 16QAM signal
- Si/SiN waveguide allow more compact chip size when more complicated systems are needed.
  - Mux/Demux
  - Waveguide routing
- Added BEOL fabrication
  - Leverage exising SiP Foundry

Further reading on the LNoI modulator technology –hybrid integration approach can be found in

- Xu, M., He, M., Zhang, H. *et al.* High-performance coherent optical modulators based on thin-film lithium niobate platform. *Nat Commun* **11,** 3911 (2020).
- He M, Xu M, Ren Y, et al. High-performance hybrid silicon and lithium niobate Mach–Zehnder modulators for 100 Gbit s^{-1} and beyond[J]. Nature Photonics, 2019, 13(5): 359-364.





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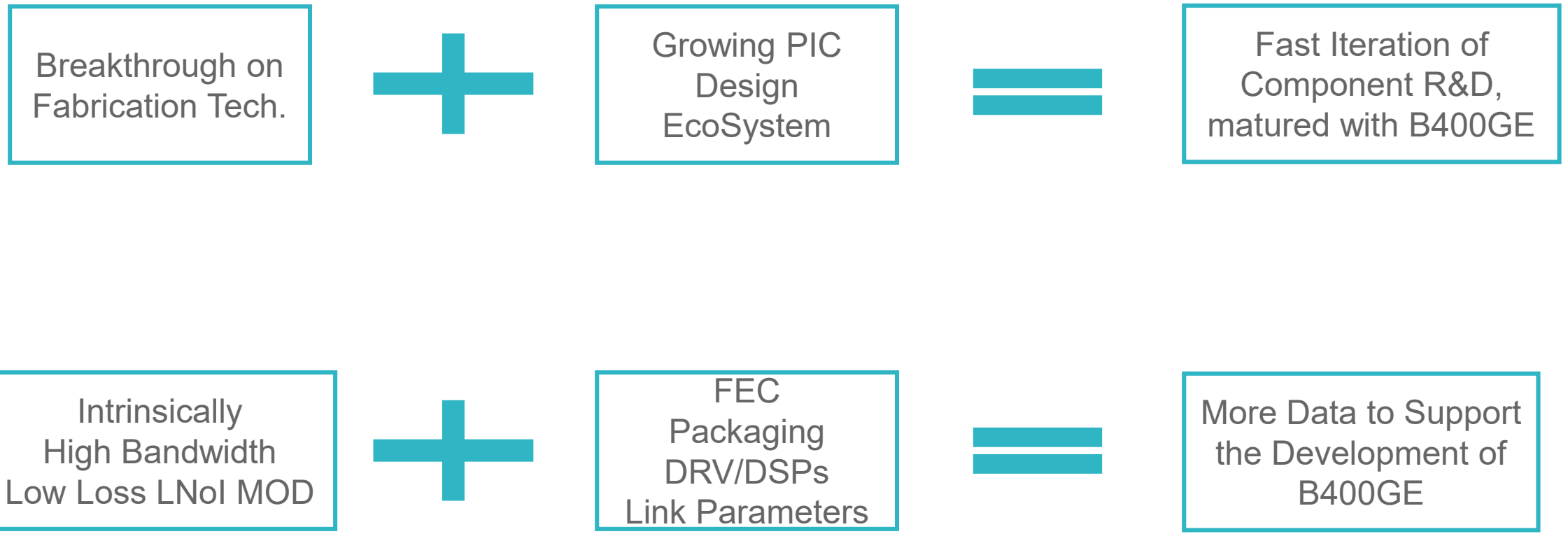
Breakthrough on Fabrication Tech.
Growing PIC Design EcoSystem
Fast Iteration of Component R&D, matured with B400GE
Intrinsically High Bandwidth Low Loss LNoI MOD
FEC Packaging DRV/DSPs Link Parameters
More Data to Support the Development of B400GE

Future work to be done

- Test of 200G signaling using improved modulator and packaging
  - Investigate 200G PAM4 link for at least 2km, and investigate its capability of operation over up to 10km link
  - Test against various working condition
- Demonstration of Coherent modulator @130GBd 16QAM for 800Gbps
  - Investigate Optical link properties
  - Investigate Optical link capabilities on OSNR and BER to facilitate discussion on BER and FEC

Thank you.

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