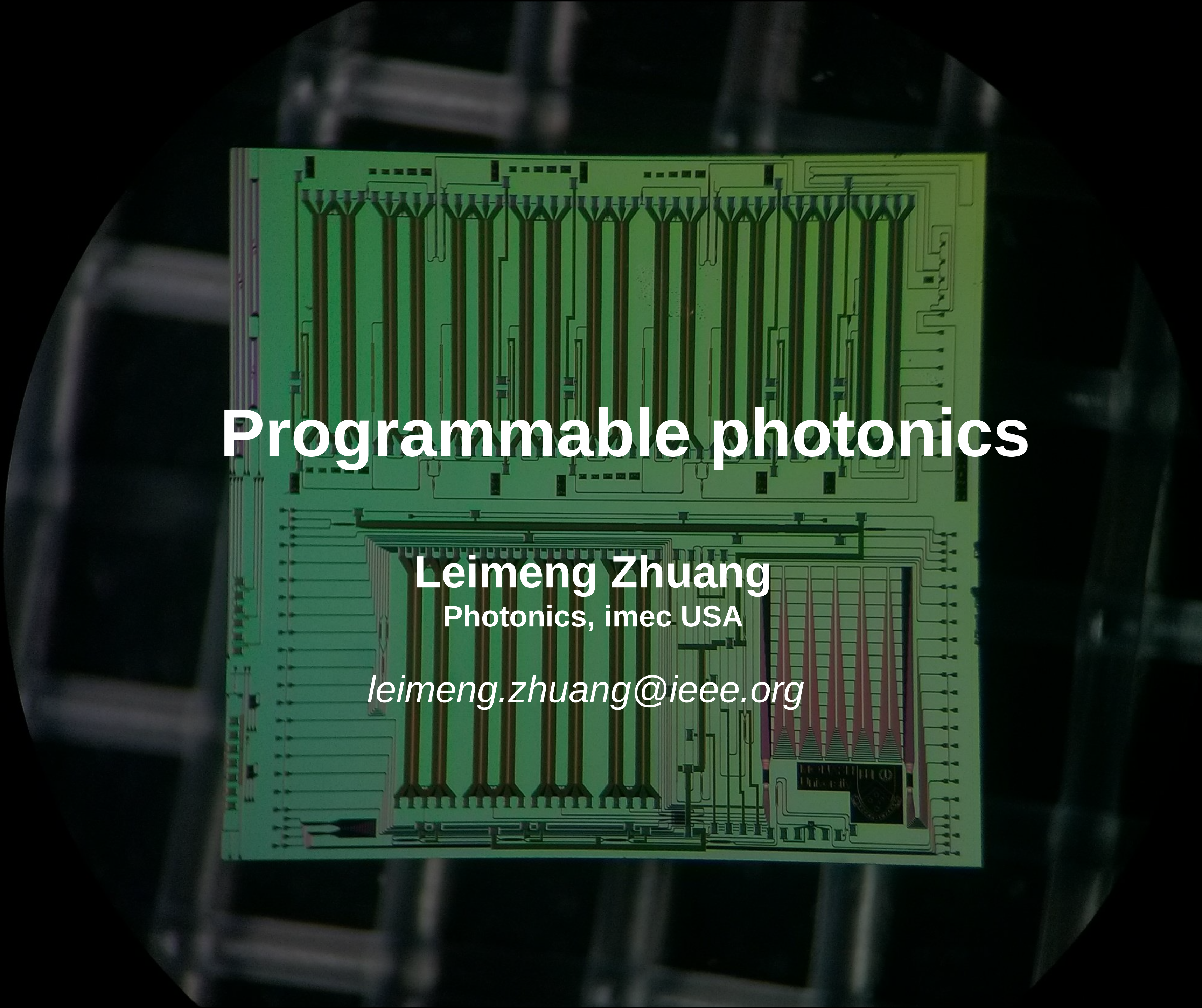


Programmable photonics

Leimeng Zhuang

Photonics, imec USA

leimeng.zhuang@ieee.org

Imec world map

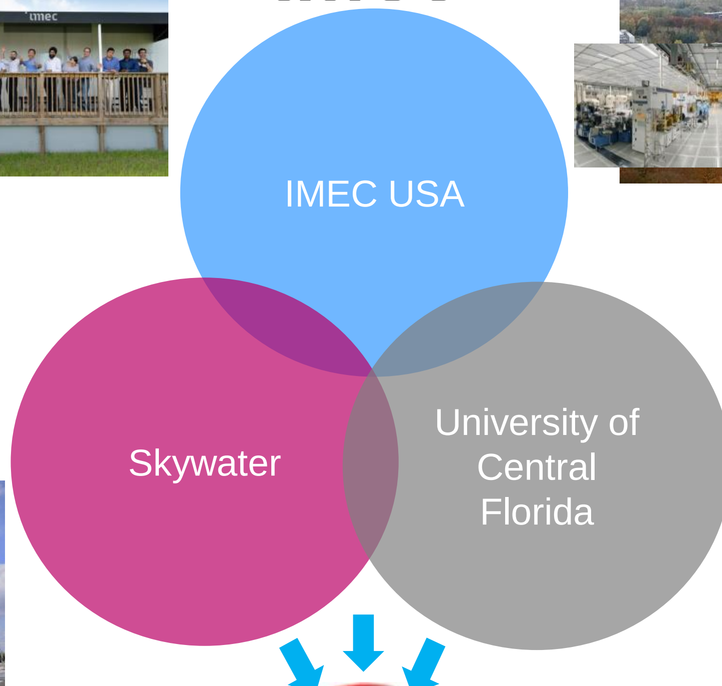
Imec USA

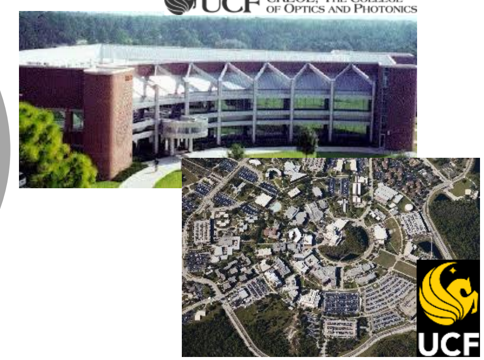
Opened in 2016
500 acre technology district part of Osceola County's **NeoCity** initiative located in Kissimmee, Florida

Partnered with **Skywater** for fabrication

Pursuing R&D in
*Silicon photonics
*Highspeed RF electronics
*Healthcare in space

Local photonics eco system





skywater

Florida Photonics Cluster

Currently, more than 60 members
Photonics, Optics, Precision, Material, Electronics, Measurement, Manufacturing, Publishing

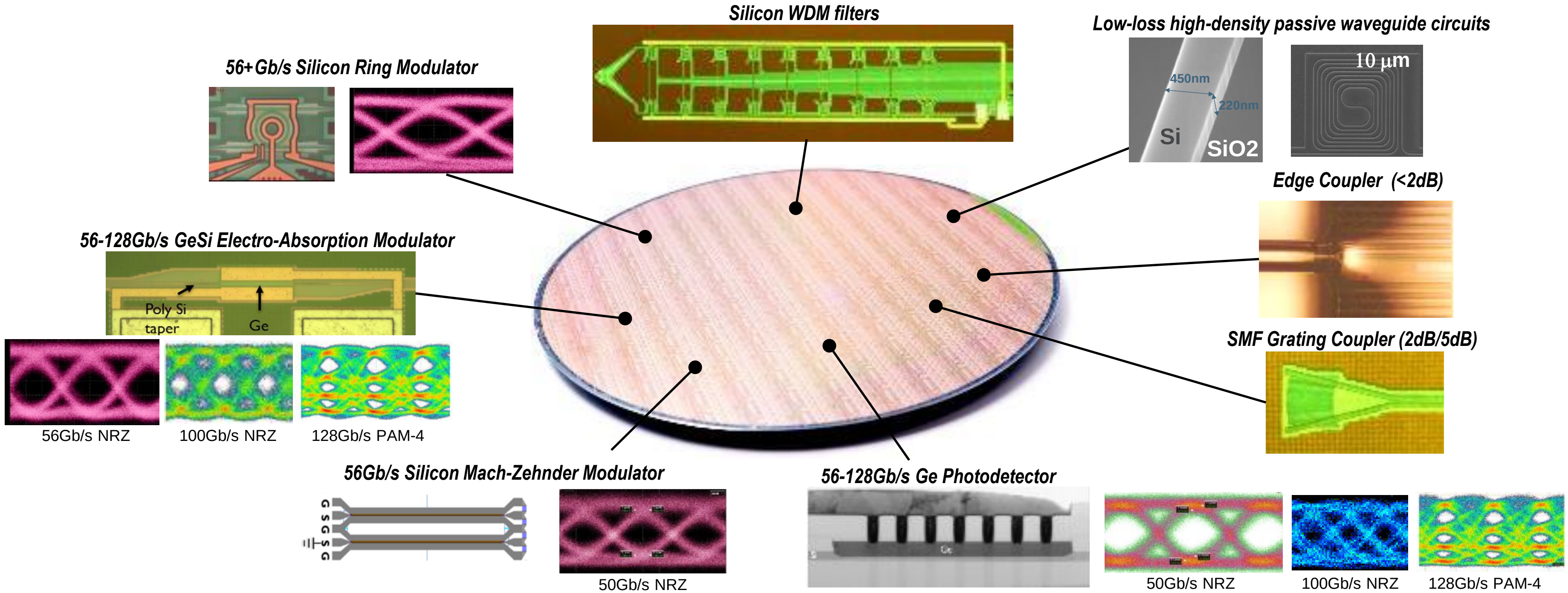
Technical content

1. imec silicon photonics platform
2. Electro-photonics
3. Programmable photonics

IMEC SILICON PHOTONICS PLATFORM

Silicon Photonics Technology Platform

INTEGRATED ON A SINGLE 200MM OR 300MM WAFER

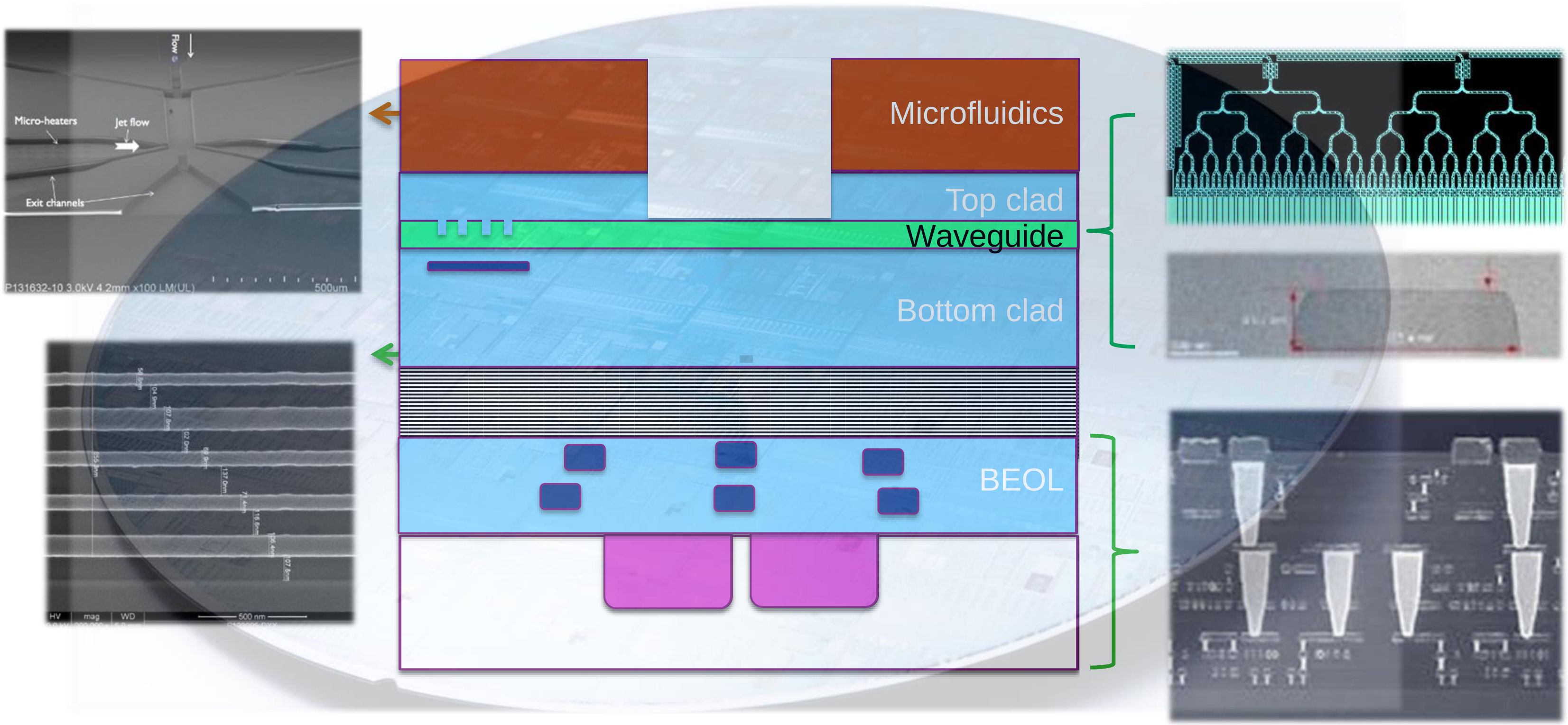


Fully Integrated Silicon Photonics Platform for 1310nm/1550nm Wavelengths

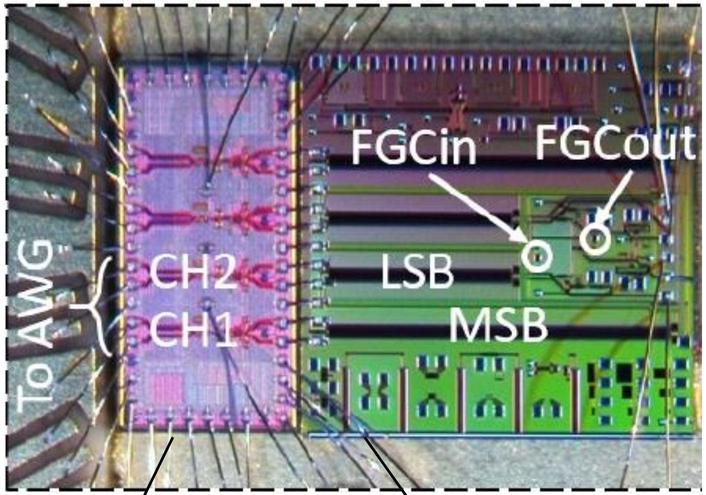
- Low-loss Passive Silicon Waveguide Devices and Fiber Coupling Structures
- 56-128Gb/s (Ge)Si Modulators and Ge(Si) Photodetectors

Integration technology

- Versatile, scalable, mature platforms accessing new materials

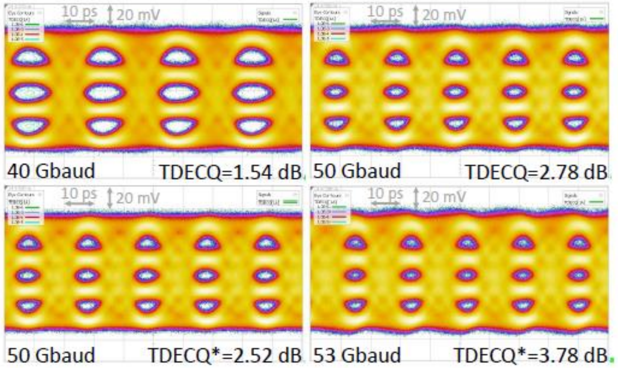


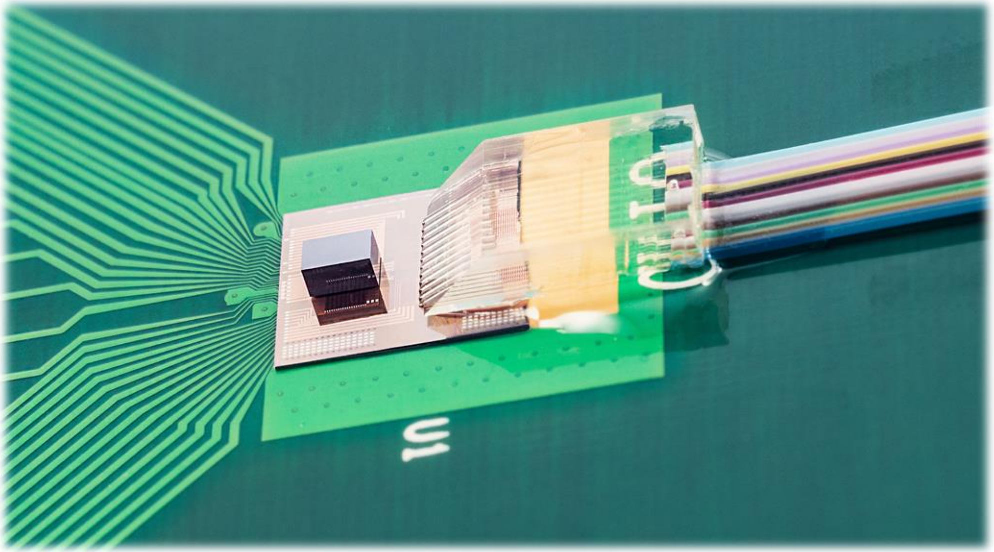
Packaging



SiGe driver array   Silicon Photonic IC

- 55nm SiGe BiCMOS technology
- Silicon Photonic modulator





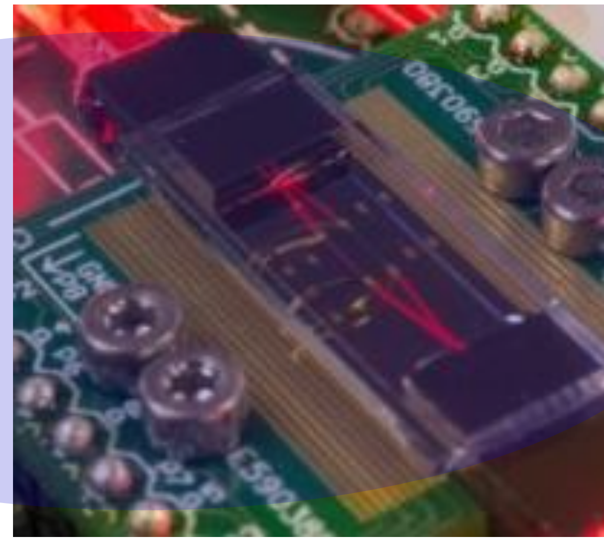
TSV-enabled Hybrid FinFET CMOS – Silicon Photonics Technology for High Density Optical I/O

Electro-photonics

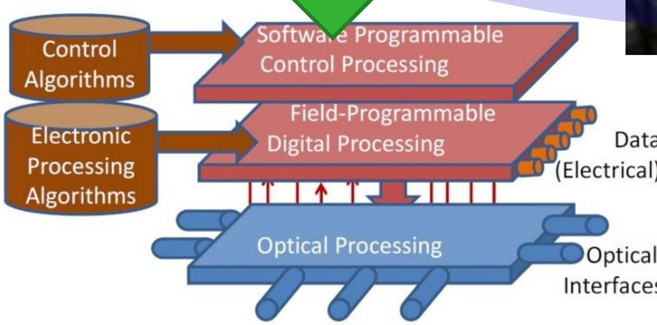
Electro-Photonics

Consider the best mix of electrical and optical technologies

Electro-Photonics



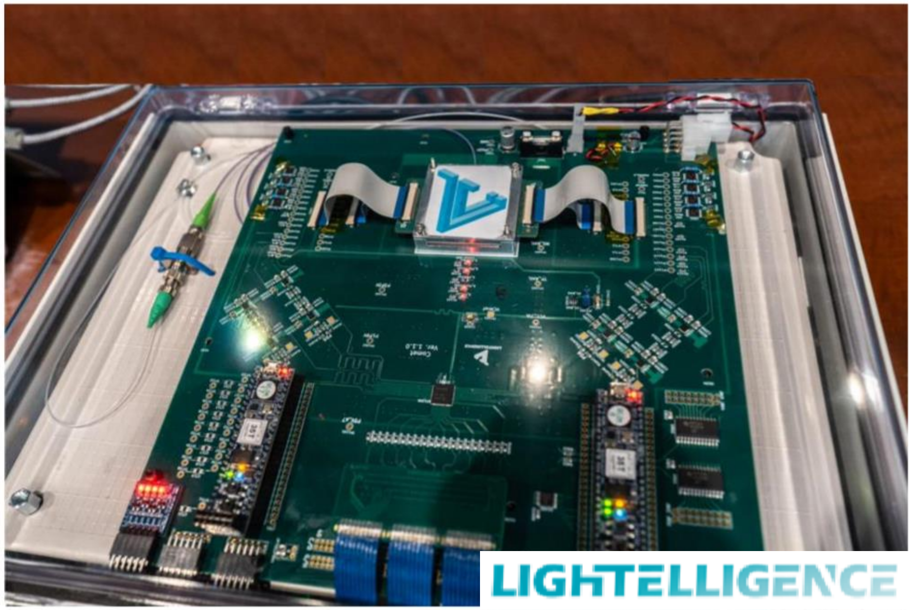
- Mature industry
- High flexibility
- Easy access to memory



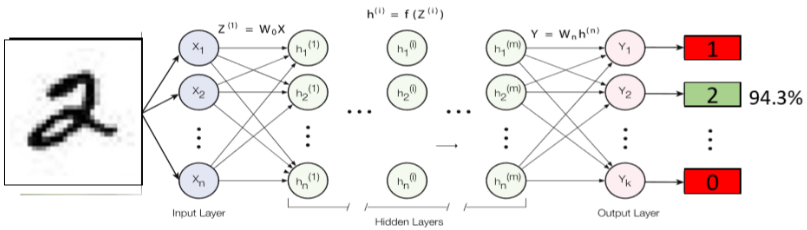
- Large bandwidth
- Energy efficient
- Strong potential for innovatio

Prof. Arthur Lowery's ARC Laureate Fellowship, "**The Electro-Photonic Interchange: A new green platform for communications signal processing**" (2013—2018).

The 1st photonic AI computer

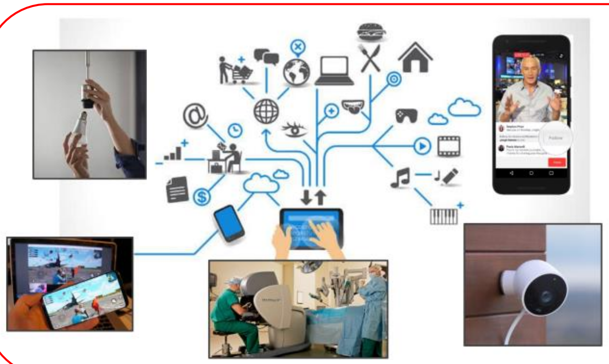


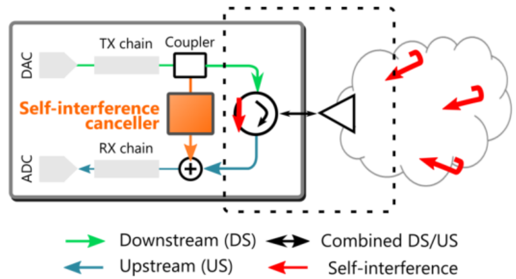
- Self-contained system
- Does not rely on lab environment
- Runs MNIST image recognition
- Better than 97% accuracy

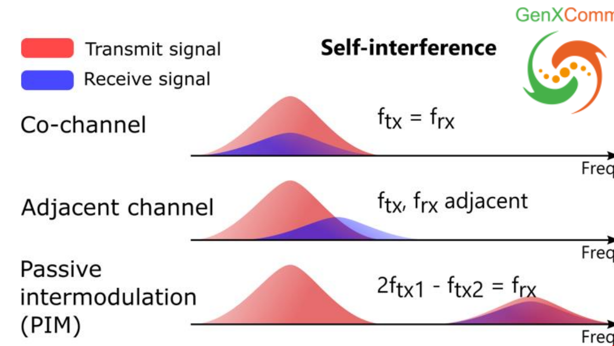


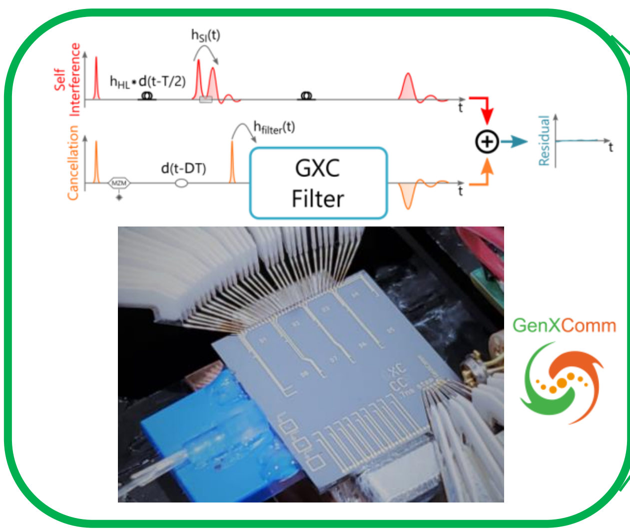
	Electronic Chip	Lightelligence Optical Chip	Improvement
Latency	100 ns	1 – 10 ps	**10,000X to 100,000X**
Energy Efficiency	1 TOPs/W	> 100 TOPs/W	**> 100X**
Through-put	30 – 100 fps	> 10,000 fps	**> 100X**

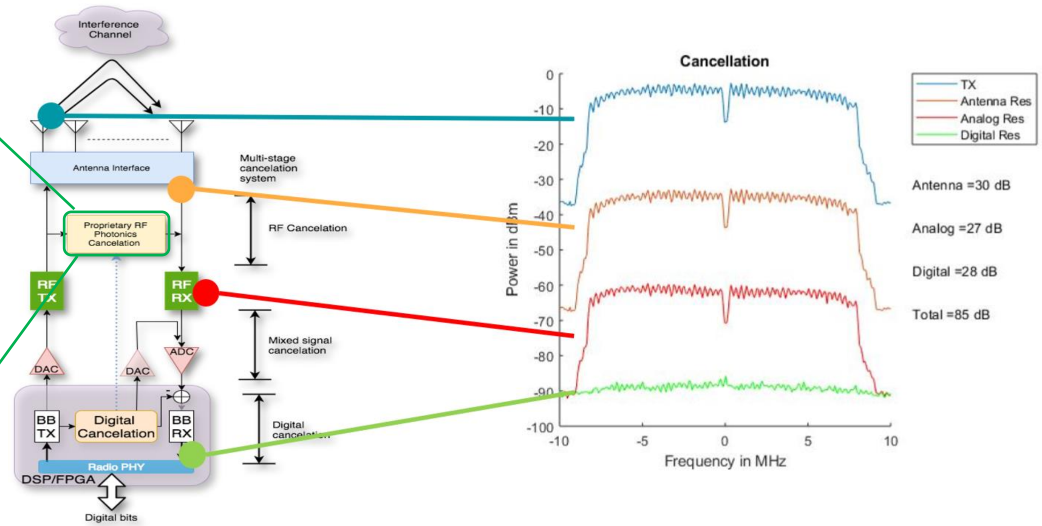
RF Self-interference cancellation



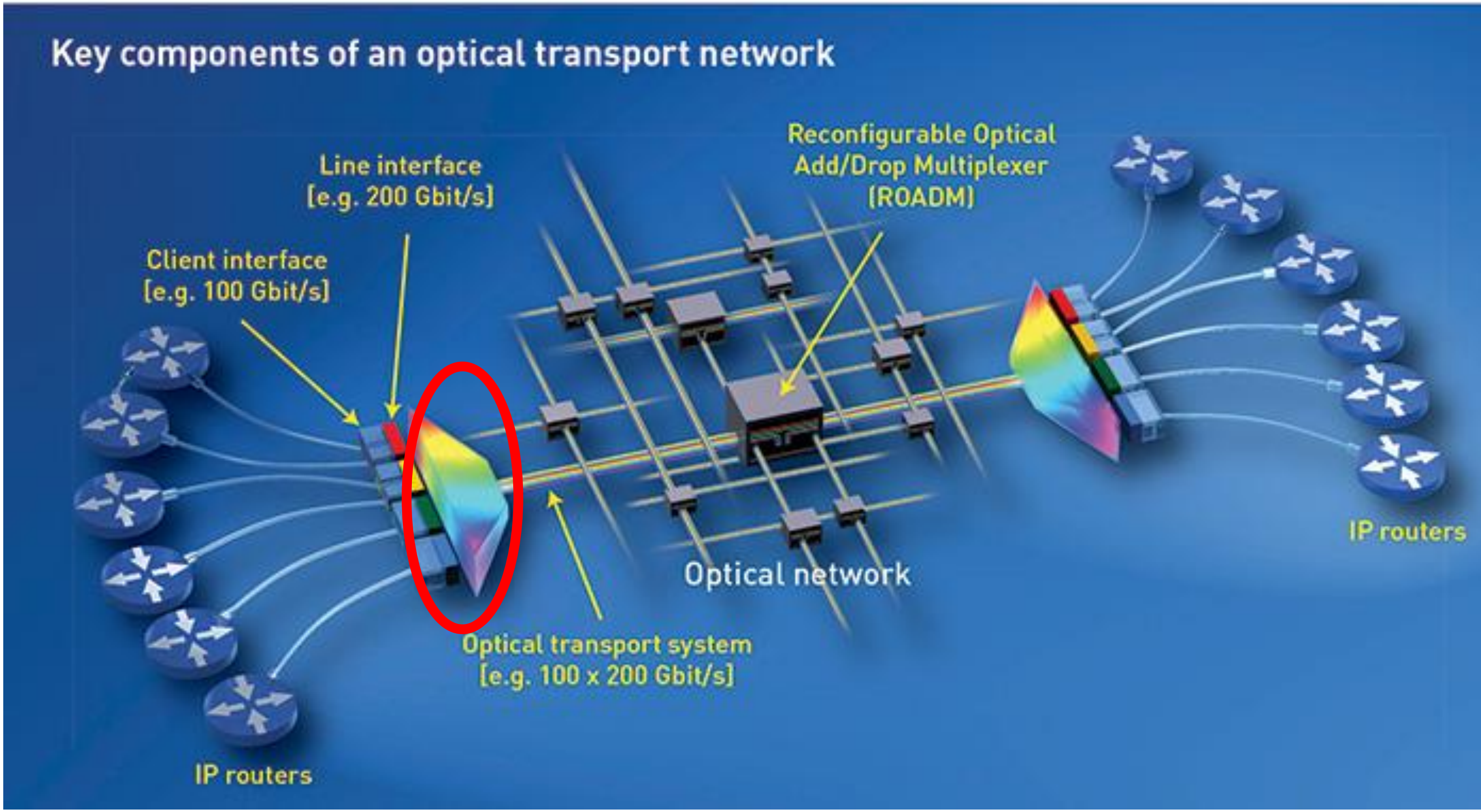




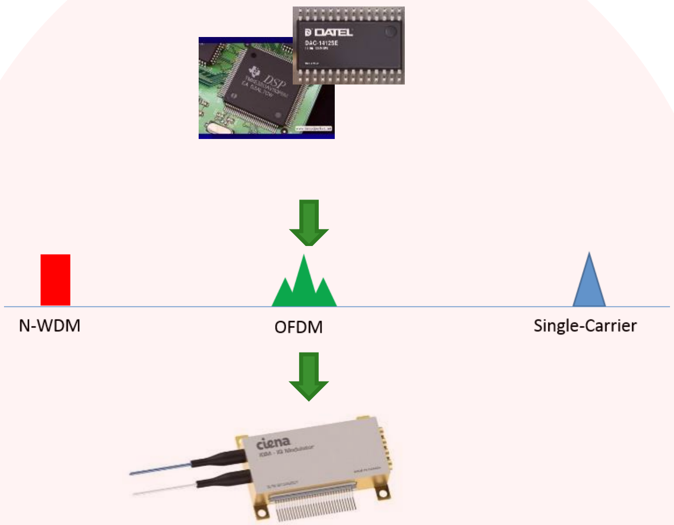




High-spectral-efficiency Tx/Rx

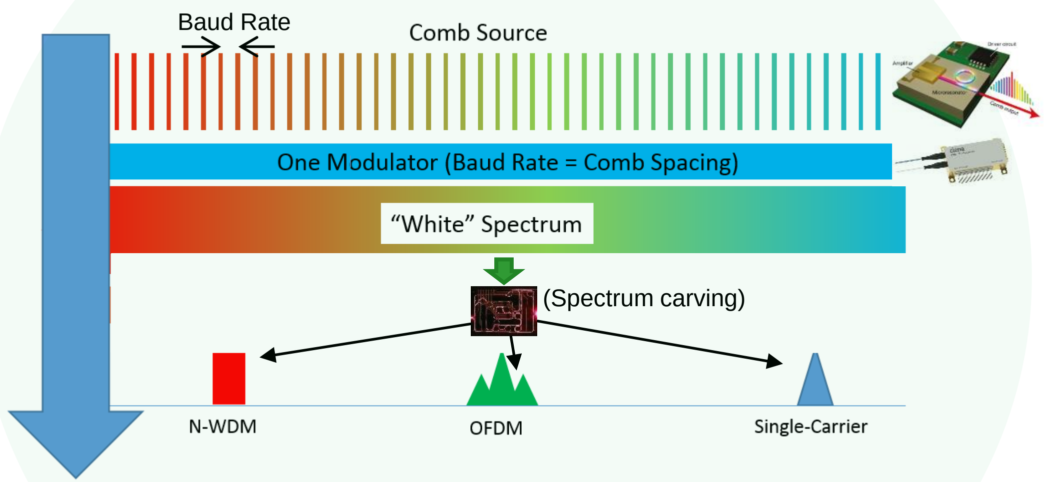


Optical pulse shaping



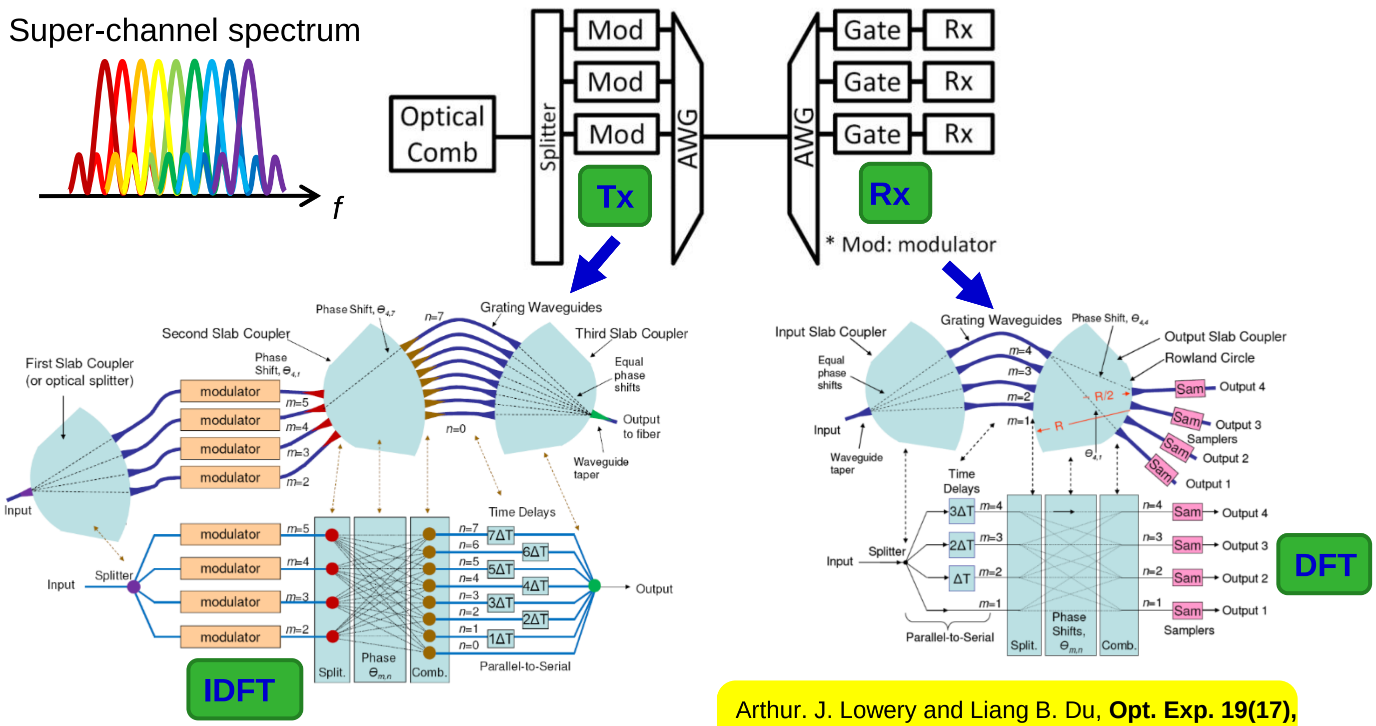
Electrical shaping (e.g. 25 Gbd/s)
- **Fast DSP**
- **Fast DAC (50GSa/s)**
- **Fast Modulator**

1. K. Lee, C. T. D. Thai, and J.-K. K. Rhee, Opt. Express **16**(6), 4023–4028 (2008)
2. Y-K. Huang, D. Qian, R. E. Saperstein, P. N. Ji, N. Cvijetic, L. Xu, and T. Wang, OFC 2009, paper, OTuM4.
3. A. .J. Lowery & L. B. Du, Opt. Exp., 19, 15696-15704 (2011)
4. J. Schröder, et al., J. Lightwave Technol., 32, (2014) pp. 752-759



Optical shaping
- **Wide spectral range**
- **Slower modulator**
- **Passive optical processor**

All-optical OFDM

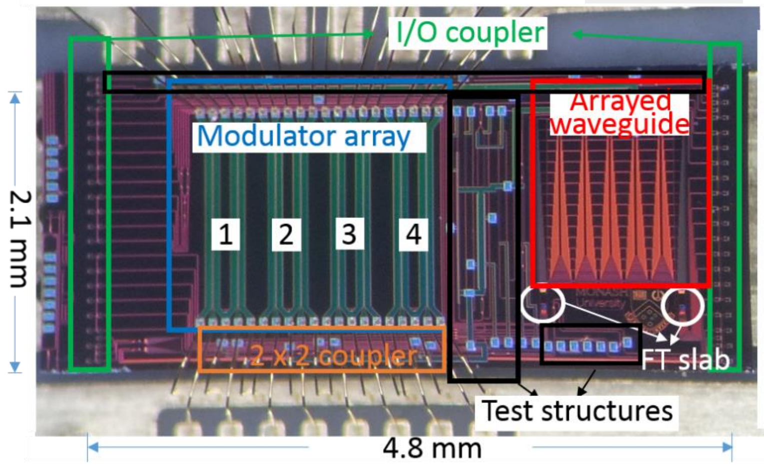


Arthur. J. Lowery and Liang B. Du, **Opt. Exp. 19(17), 15696 (2011).**
Arthur. J. Lowery, **Opt. Exp. 18(13), 14129 (2010).**

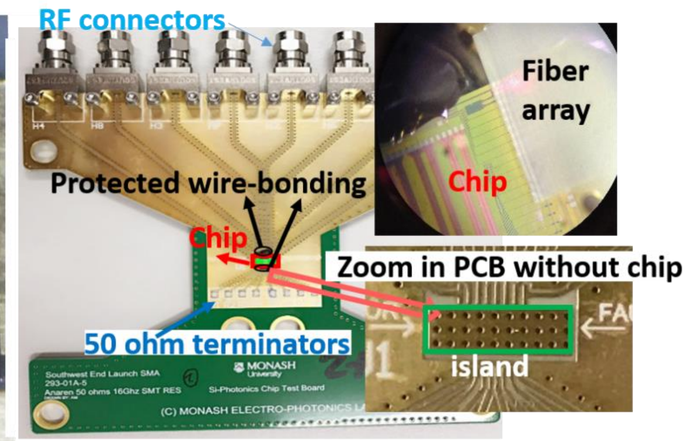
optical OFDM transmitter

(a) Photograph of OFDM Tx

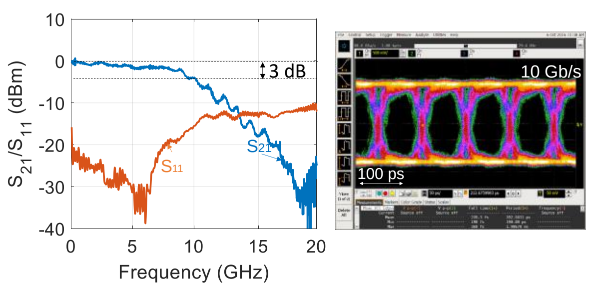
Silicon imec



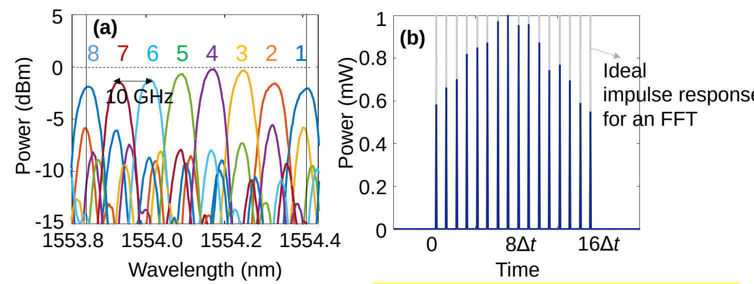
(b) Photograph of packaged OFDM Tx



Modulator characterization

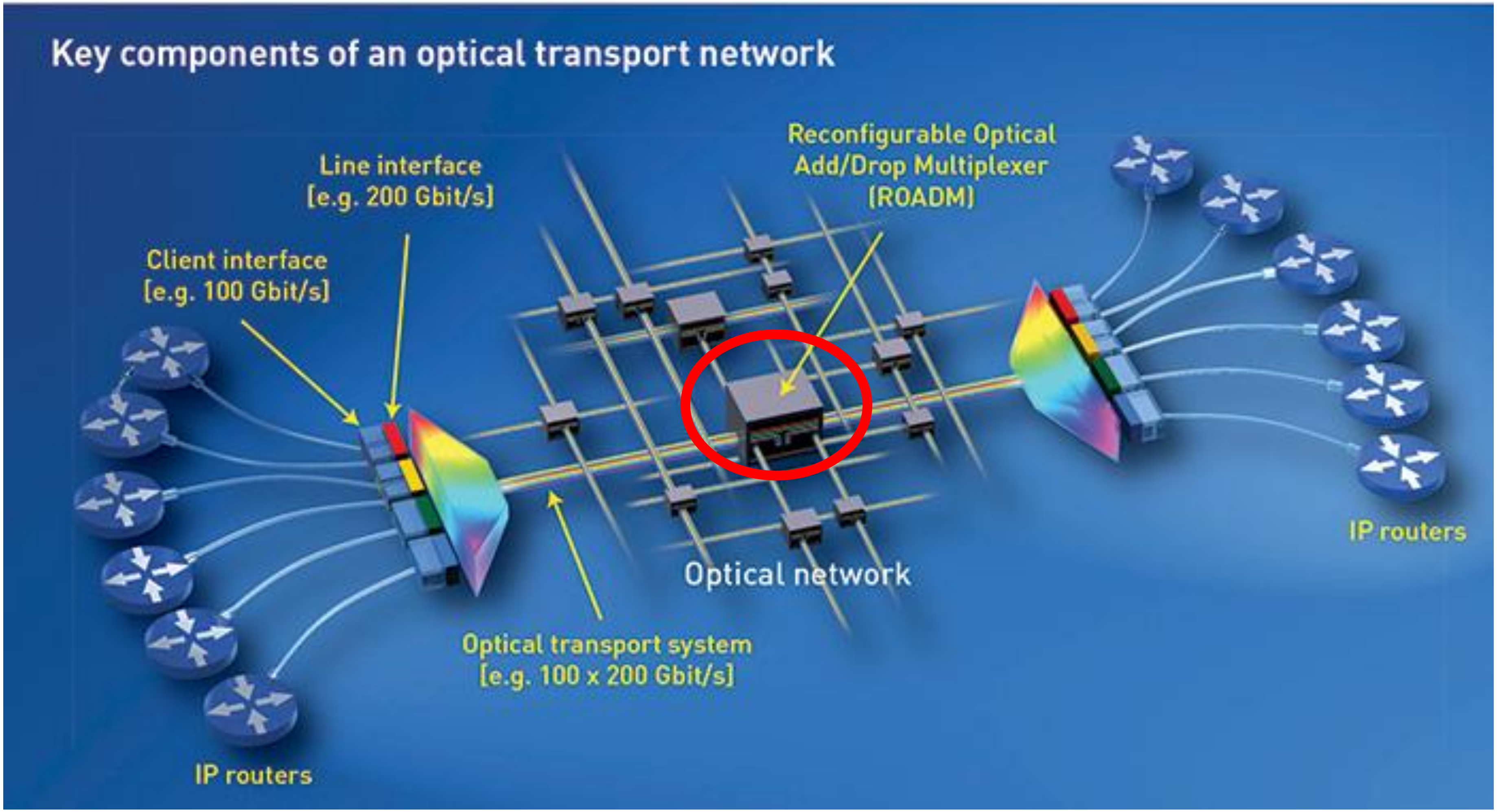


AWGR characterization

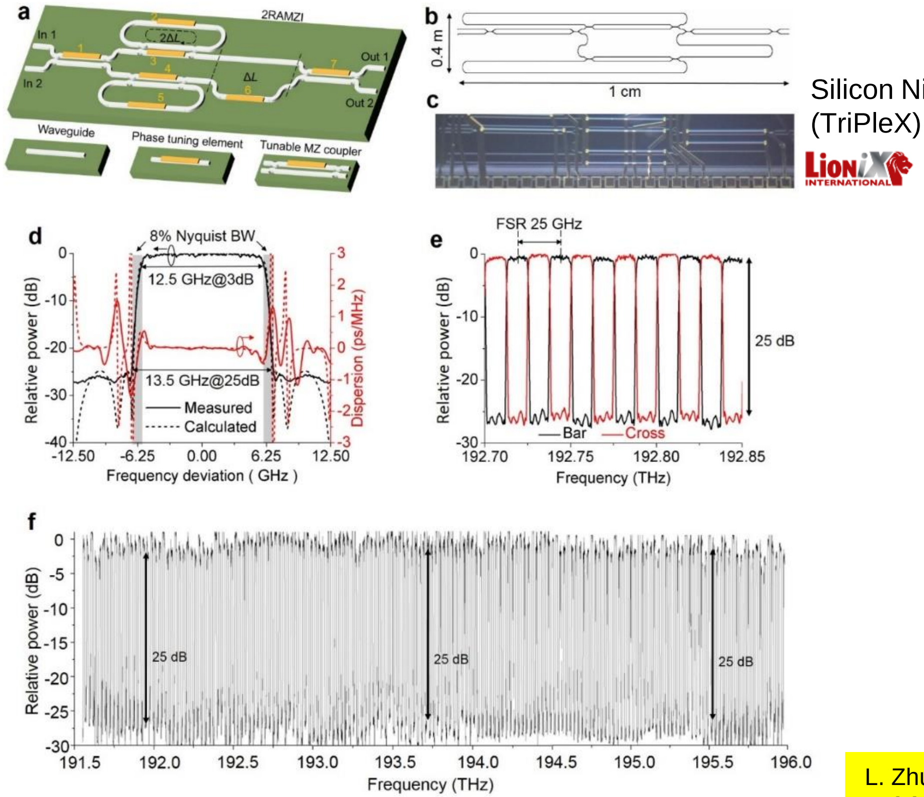


Y. Xie et al., OFC2017, W2A.9

Nyquist-WDM-superchannel ROADM



Nyquist WDM superchannel

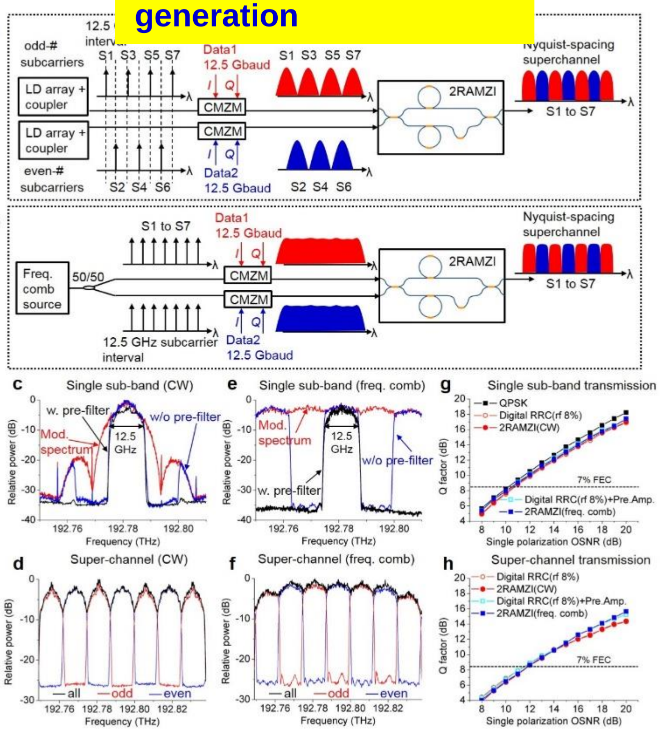


Silicon Nitride (TriPleX)

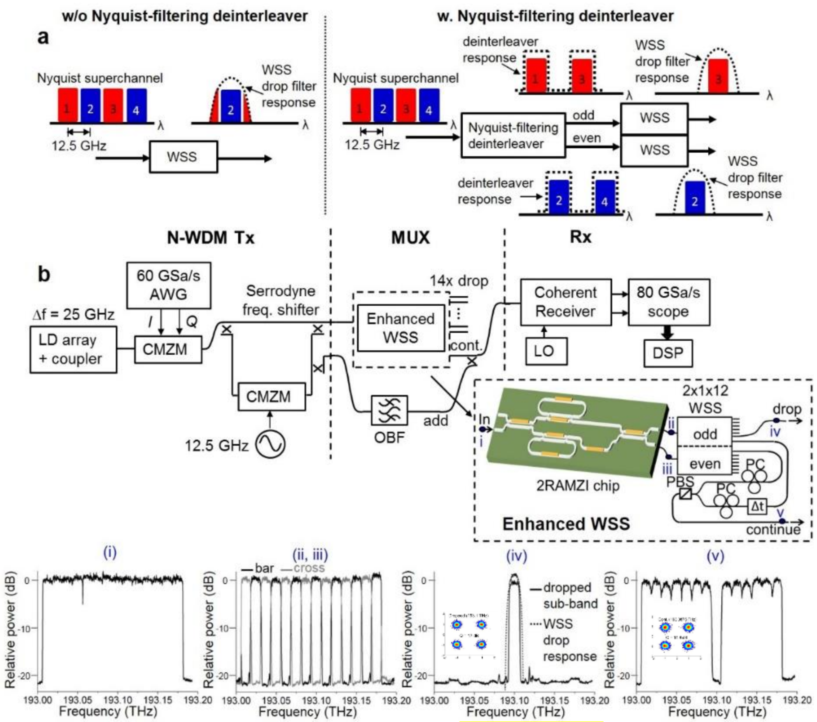
L. Zhuang et al., Opt. Express **21(7)**, 9167, 2016

Nyquist WDM superchannel

Superchannel generation



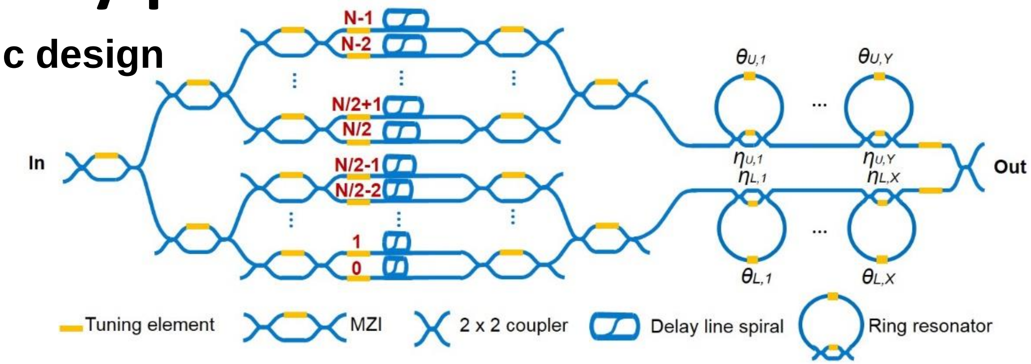
Superchannel ROADM



12.5 GHz

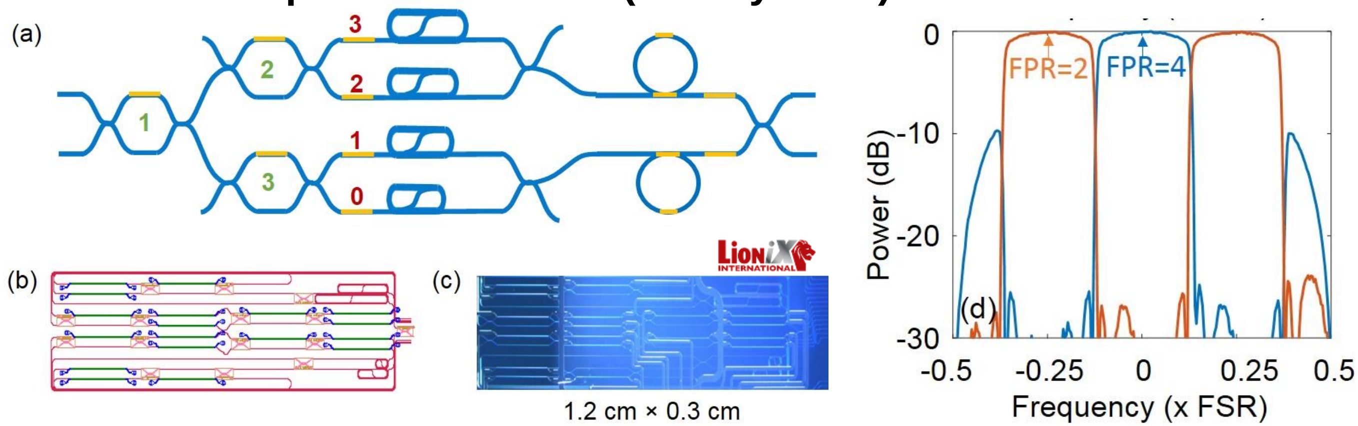
FSR-variable Nyquist WDM filter

Generic design

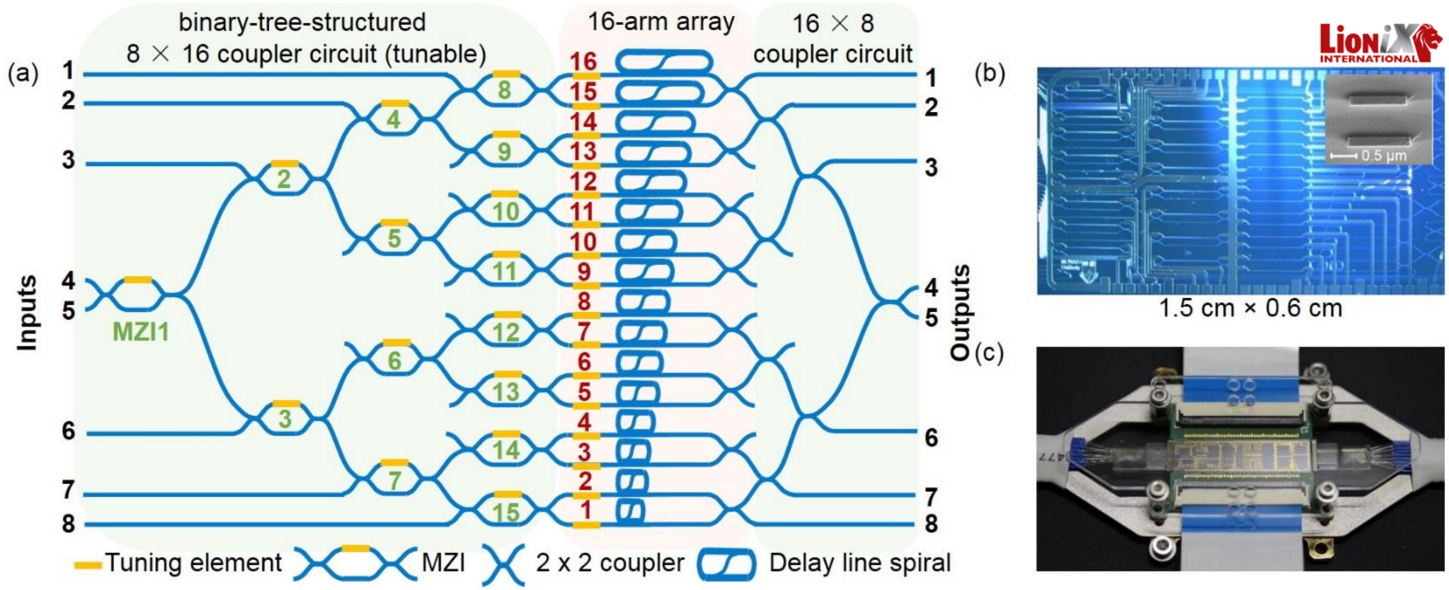


Y. Xie et al., JLT **36(13)**, 2619, 2018

Proof-of-concept demonstration (4 delay arms)



Picosecond pulse processing using a THz-BW reconfigurable chip



Nyquist pulse generation;

- 40 GHz bandwidth near rectangular spectrum, and sinc pulse with width of 25 ps

Clock rate multiplication;

- 10 Gpulse/s to 20 Gpulse/s or 40 Gpulse/s

Arbitrary waveform generation;

- Ramps, steps, sinc, square, random binary bit pattern

Tunable delays;

- 0-100 ps delays

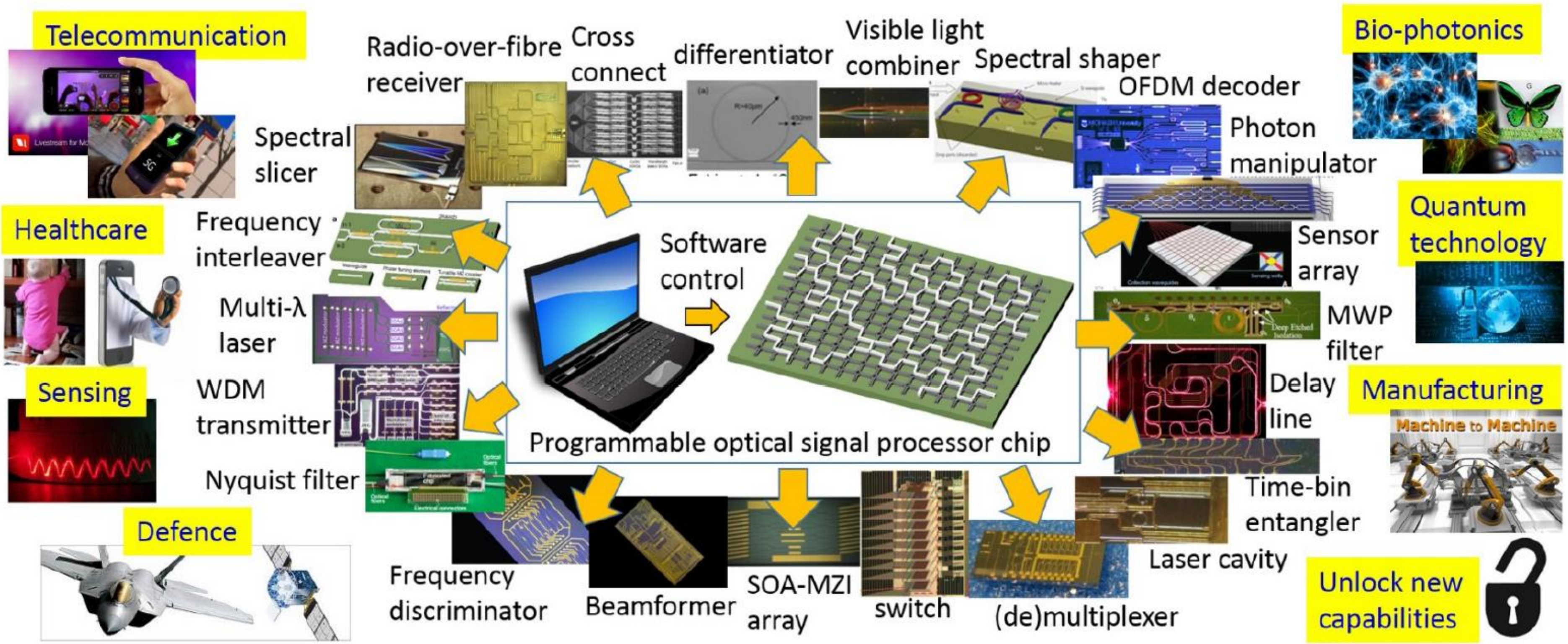
Multi-path combining;

- 10 Gpulse/s to 40 Gpulse/s

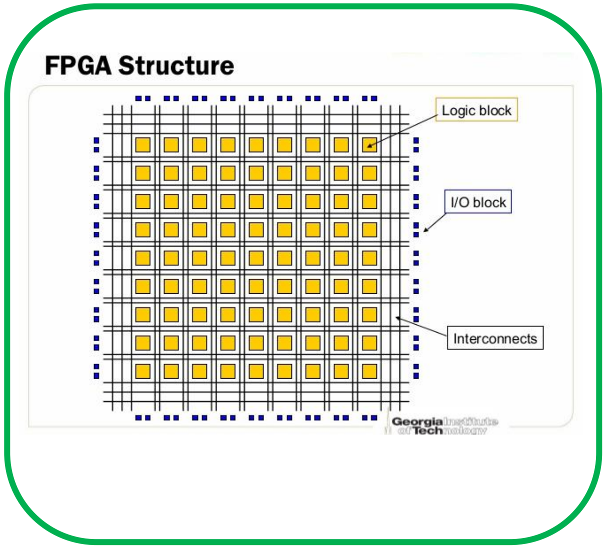
Nanophotonics -2017-0113

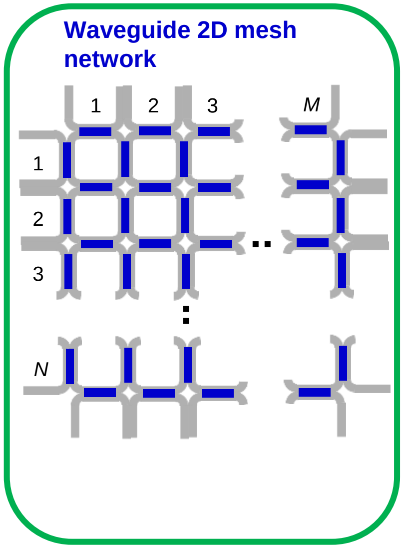
Programmable photonics

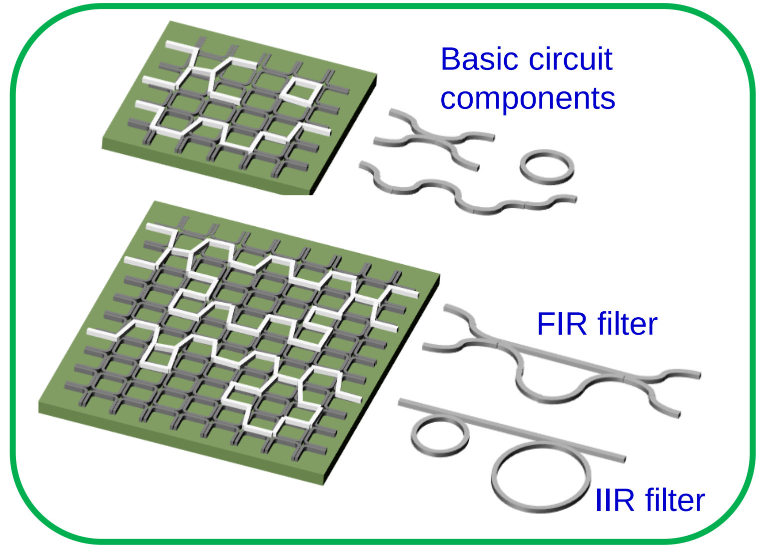
General-purpose signal processor



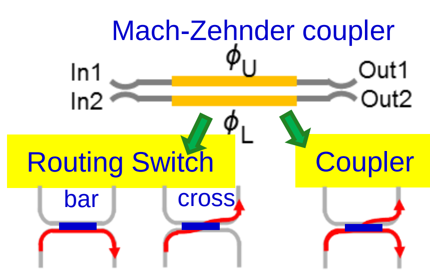
Programmable waveguide 2D mesh network

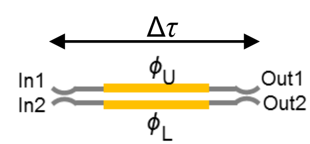






- Waveguide
- Mach-Zehnder coupler
- Phase tuning element
- Light propagation





Phase **Amplitude** **Delay**

$$C_{11} = -C_{22} = -j\exp\left(\frac{\phi U+\phi L}{2}\right)\sin\left(\frac{\phi U-\phi L}{2}\right)\exp(j2\pi f\Delta\tau)$$

$$C_{12} = C_{21} = -j\exp\left(\frac{\phi U+\phi L}{2}\right)\cos\left(\frac{\phi U-\phi L}{2}\right)\exp(j2\pi f\Delta\tau)$$

Mesh lattice

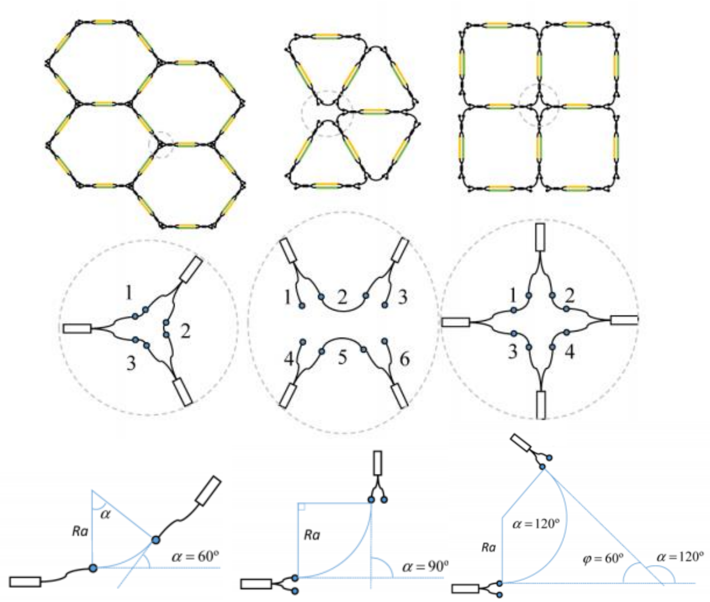
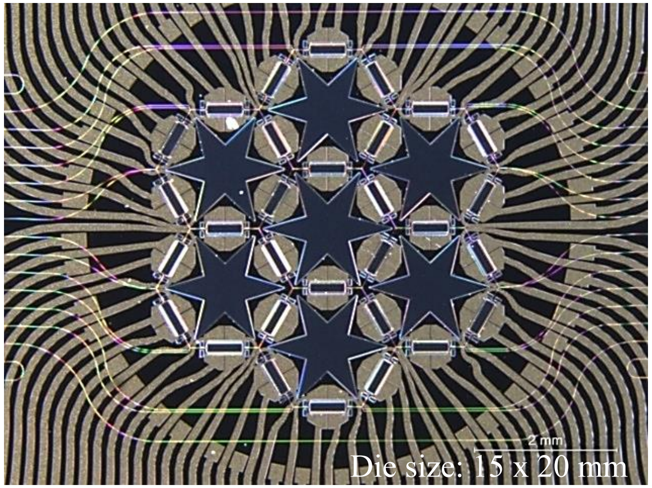
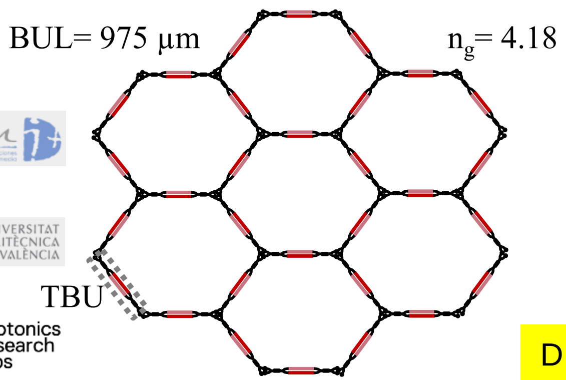


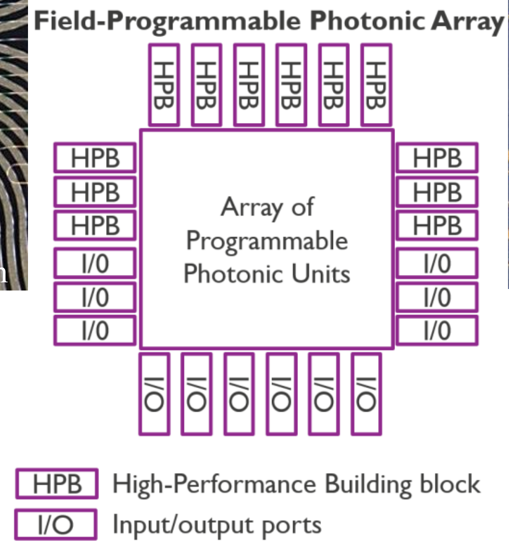
Figure of Merit	Triangular	Square	Hexagonal
ORR cavity spatial tuning resolution step in BUL units (the lower the better)	3	4	2* The first step has a resolution of 6
MZI arm imbalance spatial tuning resolution step in BUL units (the lower the better)	3	4	2
ORR reconfiguration performance (the higher the better) (for X = 25 BUL)	8	6	9
MZI reconfiguration performance (for X = 25 BUL)	8	6	12
Switching elements per unit area (the lower the better for a fixed value of reconfiguration performance)	3.96	2.40	1.52
Replication Ratio for ORR structures up to 16 BUL cavity length (the higher the better).	1	2.68	1.31
Replication Ratio for MZI structures up to 12 BUL cavity length (the higher the better).	1	3	1.31
Laccess/Laccess square % for a fixed Ra (the lower the better)	+ 33.33%	+ 0.00%	33.33%
Ra/Rasquare % for a fixed BUL (the higher the better)	25.00%	+ 0.00%	+ 50.00%

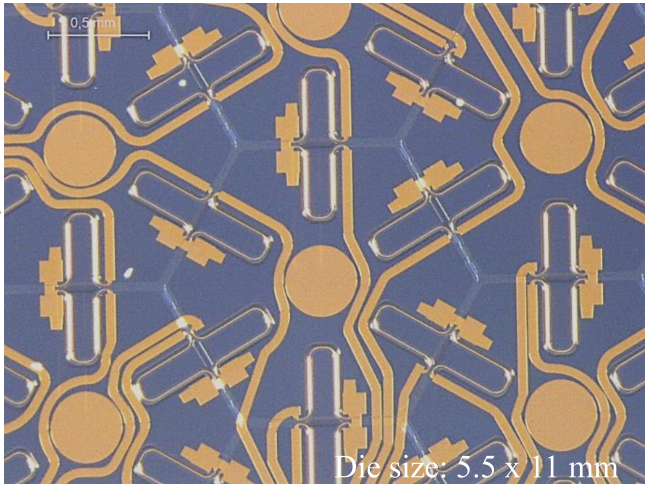
D. Pérez et al., Opt. Express 24(11), 12093, 2016

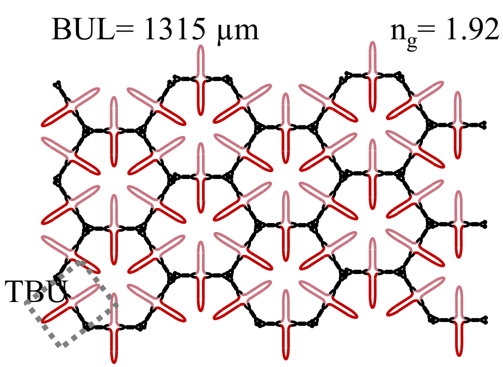
Field programmable photonic array: reconfigurable core







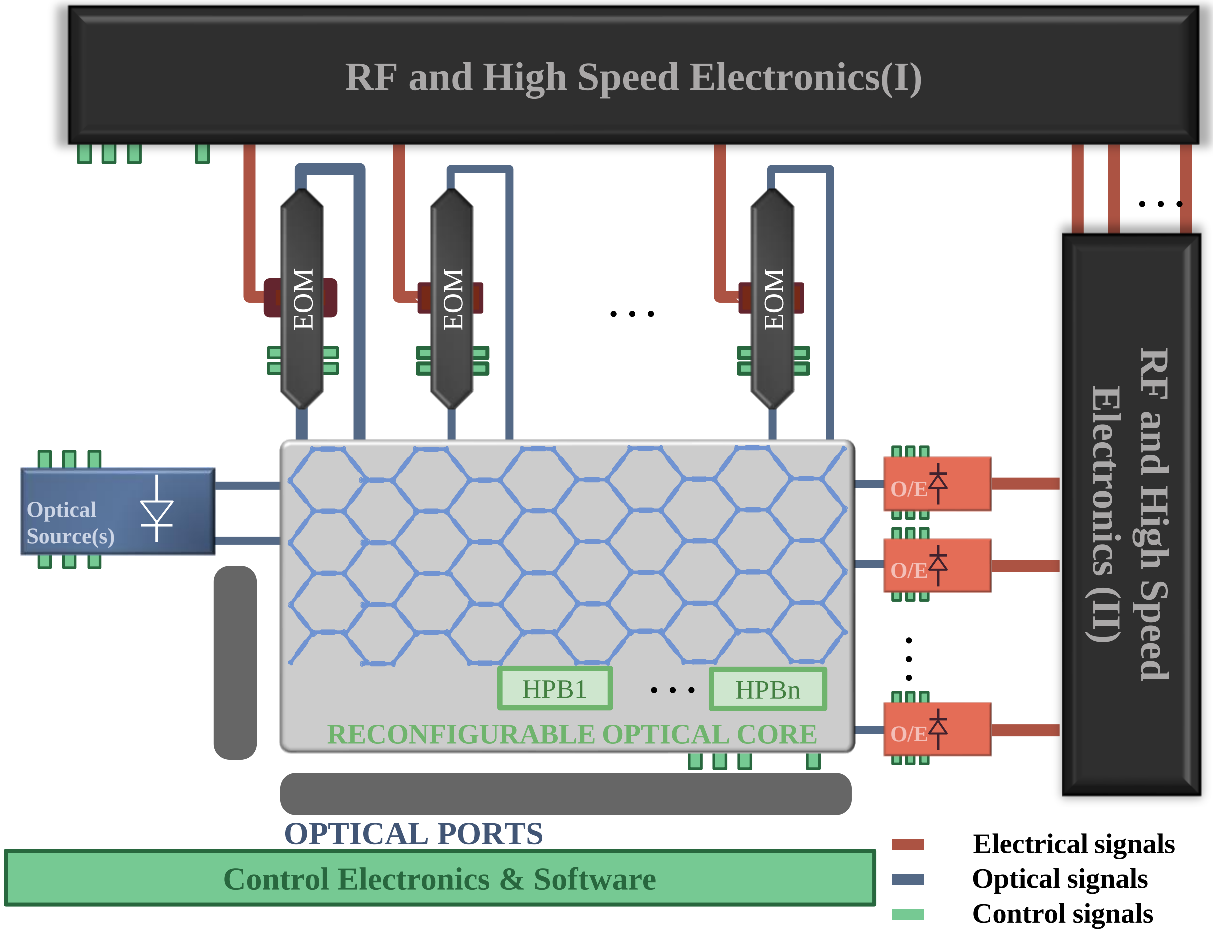




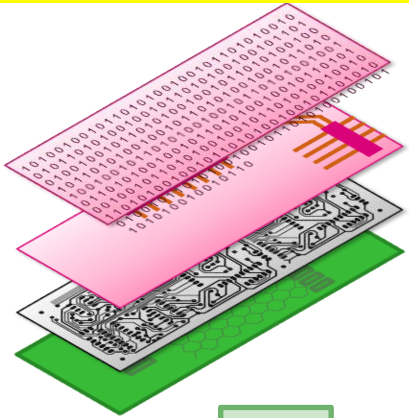
iTEAM
UNIVERSITAT POLITÈCNICA DE VALÈNCIA
Photonics Research Labs

D. Pérez, et al., "Multipurpose silicon
photonics signal processor core,"
Nat. Comms, 8, 636, (2017).

Future perspective



D. Pérez, I. Gasulla, J. Capmany, “Field-programmable photonic arrays ” Optics Express, Vol. 26, no. 21, p.27265, (2017)

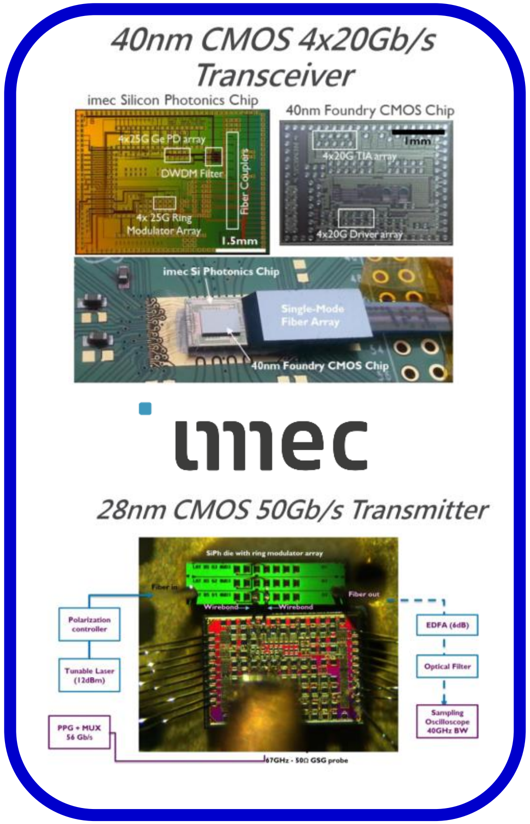


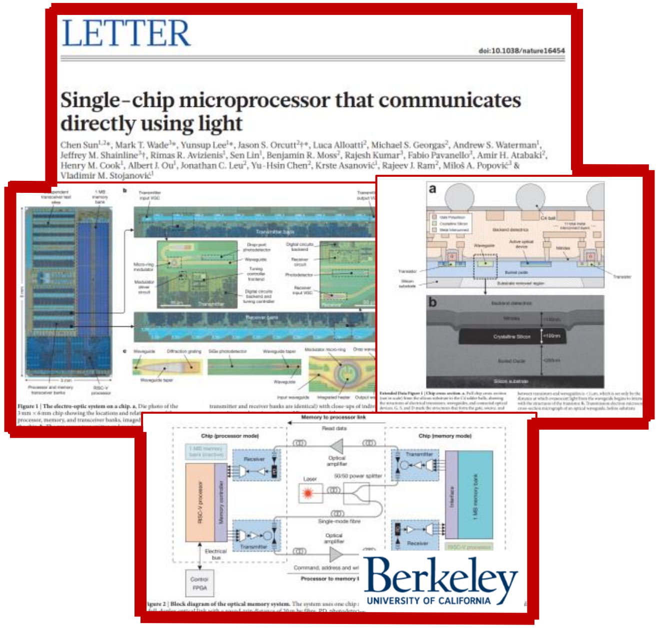
HPB

High-Performance Building Blocks:

- Delay line array
- Narrowband High-Q filters
- Amplification
- MUX/DEMUX
- Electro-optic Modulators
- Photodetectors
- Optical sources
- …

Future hardware platform





Conclusion

- Combining signal processing in both electrical and optical domain brings clear benefit for transmission capacity and power efficiency
- Field programmability increases the potential for applications of optical signal processors
- Advancing in hybrid electronics-photonics integration technologies promise a robust hardware platform

Thank you for your attention

leimeng.zhuang@ieee.org