Electronics-Photonics Integration in Advanced CMOS Platforms Using a Photonics Module: a Transceiver Application in 65nm Bulk CMOS

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*** Work carried out at the ECEE Department of University of Colorado at Boulder**

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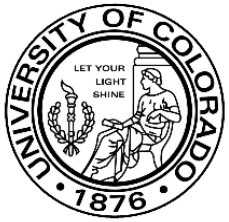
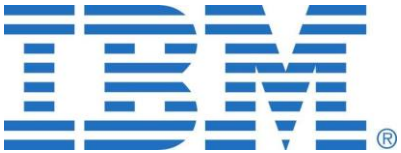
The partners in POEM





Outline

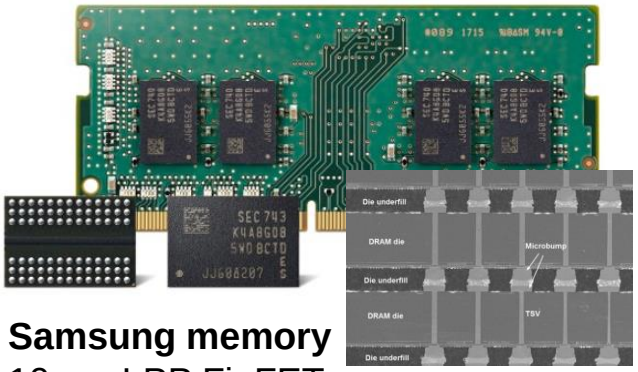
- **Why photonics in bulk CMOS platforms?**
- **Current approaches for photonic transceivers**
- **Introducing a photonics module in CMOS platforms: challenges and benefits**
- **Basic building blocks**
- **Energy-efficient and high-BW density transceivers in a 65 nm bulk node**

Beyond Standalone Transceivers: Optical I/O for CMOS

- Computing performance are limited by the electrical I/O bandwidth
- Optical transceivers on CMOS can address I/O limitation

Broadcom Tomahawk Switch
16 nm FinFET

NVidia P100 GPU
16 nm FinFET



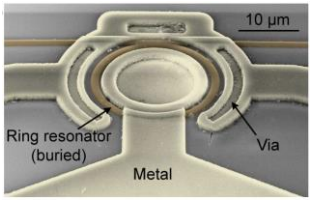
Samsung memory
10 nm LPP FinFET
DRAM stacks

Polysilicon exists in every CMOS technology and can be used for photonics

Polysilicon photonics

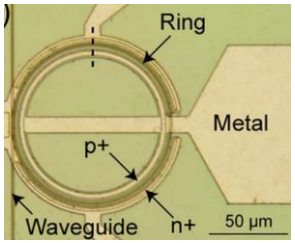
- Discrete passive and active components

Modulator



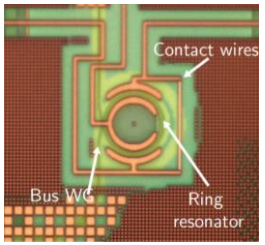
K Preston Opt. Ex. 2009
Lipson Group

Photodetector



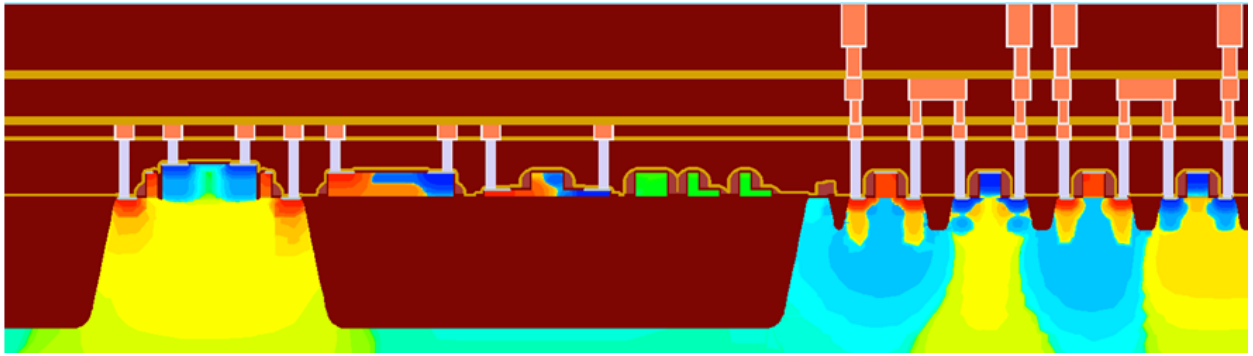
K Preston Opt. Lett. 2010
Lipson Group

Photodetector



K Mehta Opt. Lett. 2014

- Electronic-photonic integrated systems in 0.18 um CMOS



Sun et al., *JCCS* 2015

R. Meade, *VLSI* 2014

Moving towards integration with state-of-the-art CMOS

Photonics module: challenges and benefits

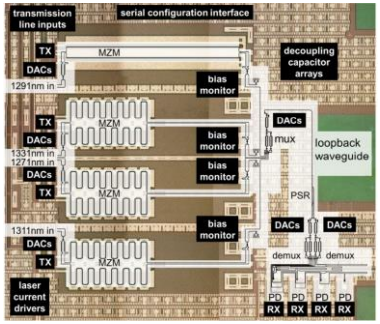
Transceiver solutions:

Monolithic (SOI)

- High sensitivity receivers
- More power efficient

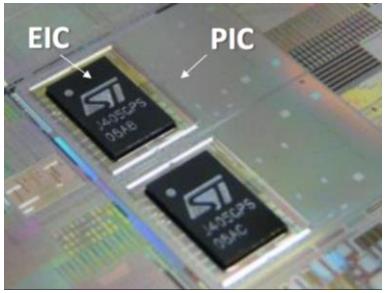
IBM

Orcutt et al., OFC 2016



Heterogeneous (SOI+Bulk Si)

- Flexibility in choosing photonics and CMOS separately



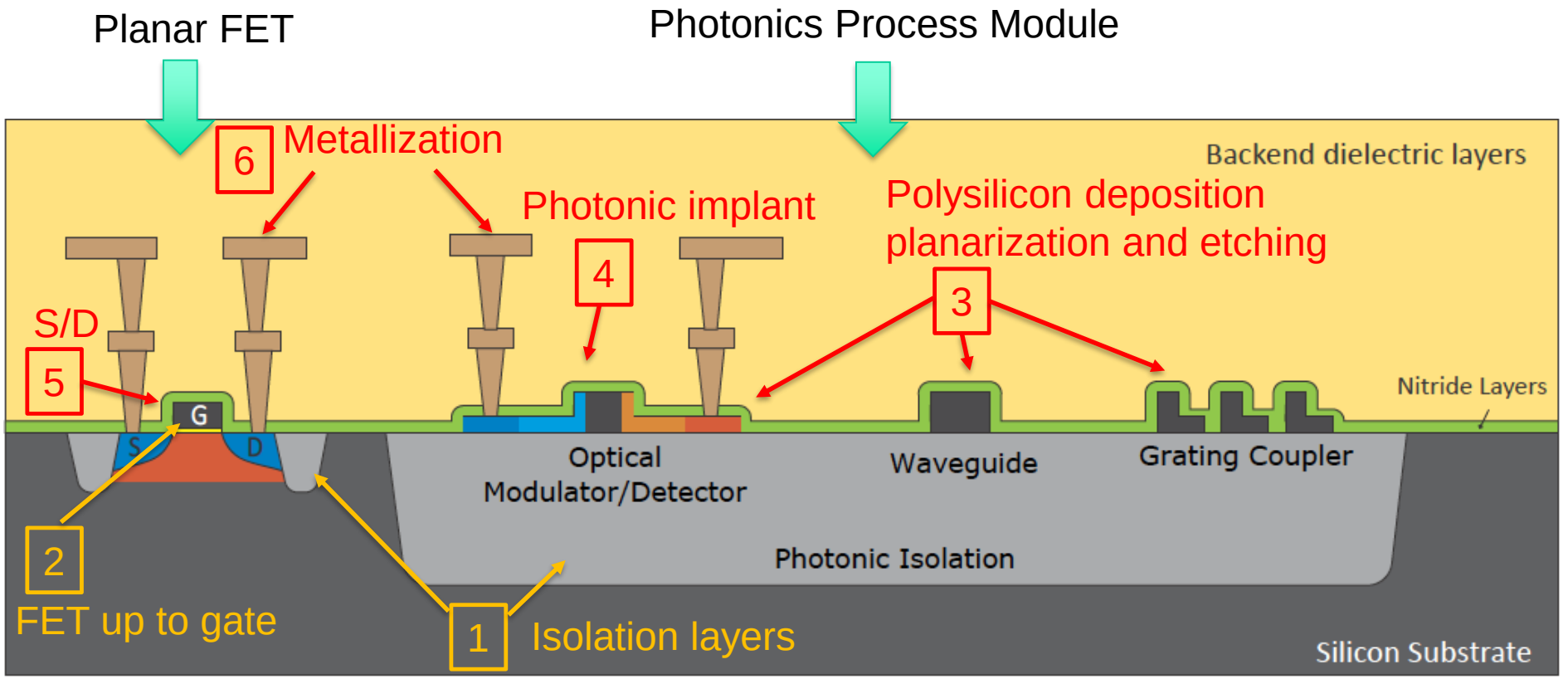
ST/Luxtera

Boeuf et al., OFC 2015

Combining the advantages of the two solutions by integrating photonics on bulk CMOS

Photonics module: integration

- Suitable integration in some of the most deeply scaled CMOS processes: planar bulk, finFET bulk and FD-SOI CMOS
- Can easily achieve 25 Gb/s for transmit and receive

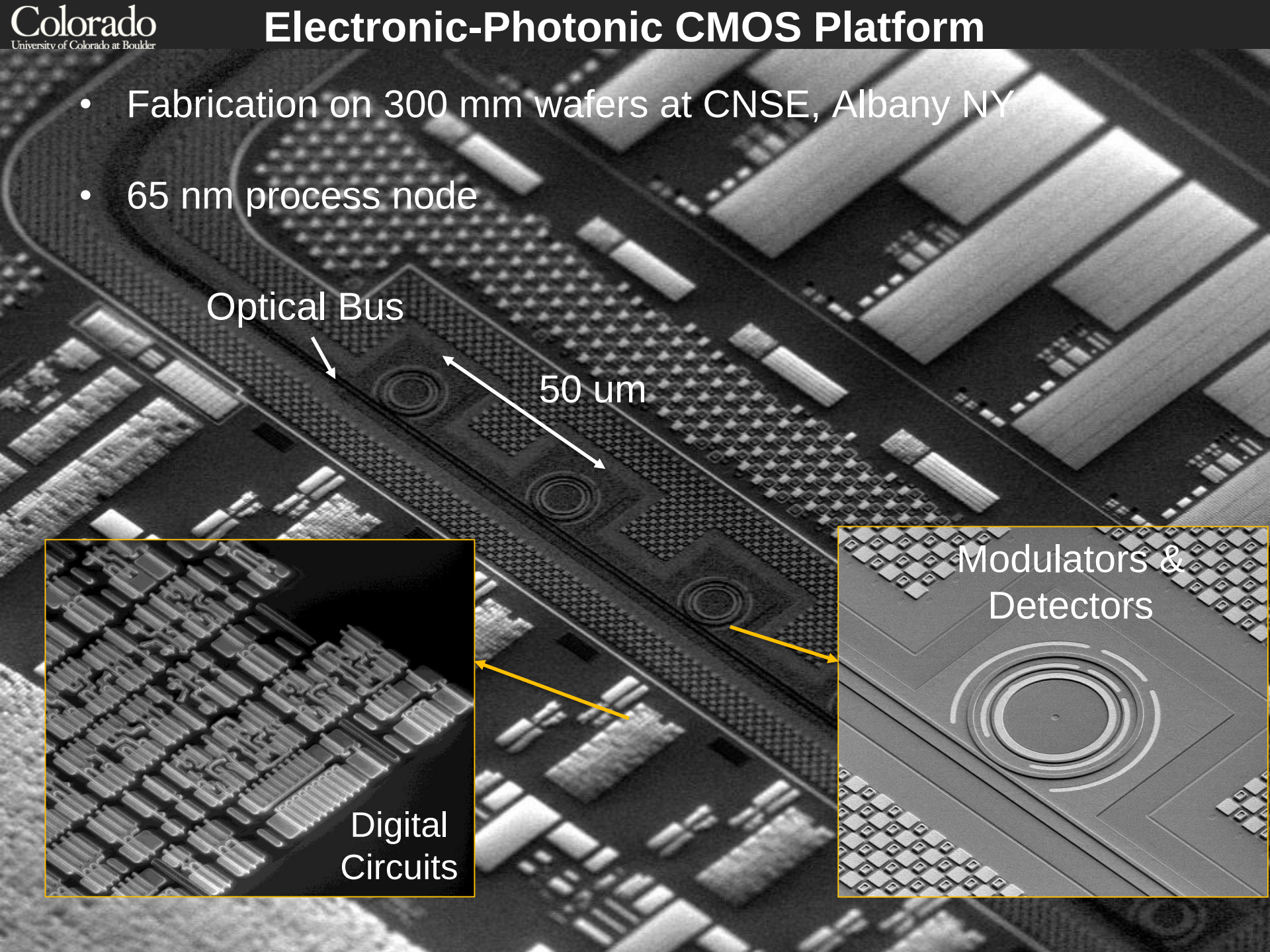


Photonics added with only 6 lithography masks

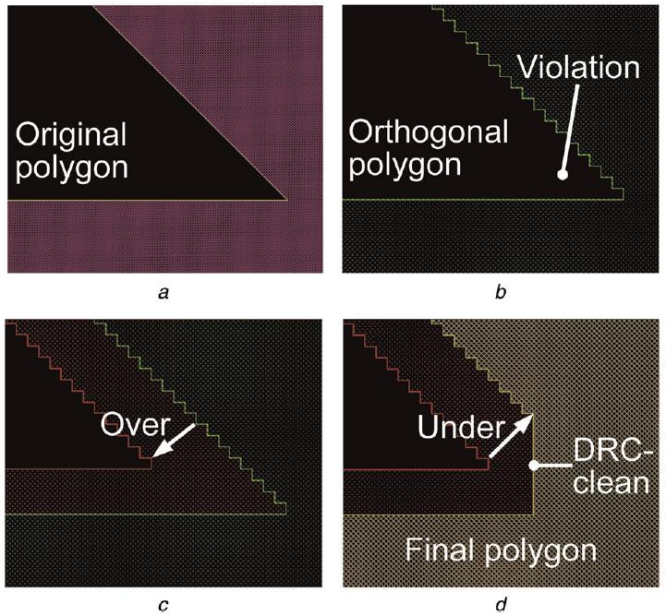
Colorado
University of Colorado at Boulder

Electronic-Photonic CMOS Platform

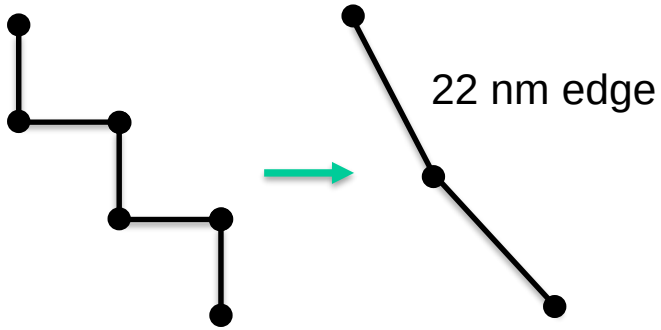
- Fabrication on 300 mm wafers at CNSE, Albany NY
- 65 nm process node



Device design and layout



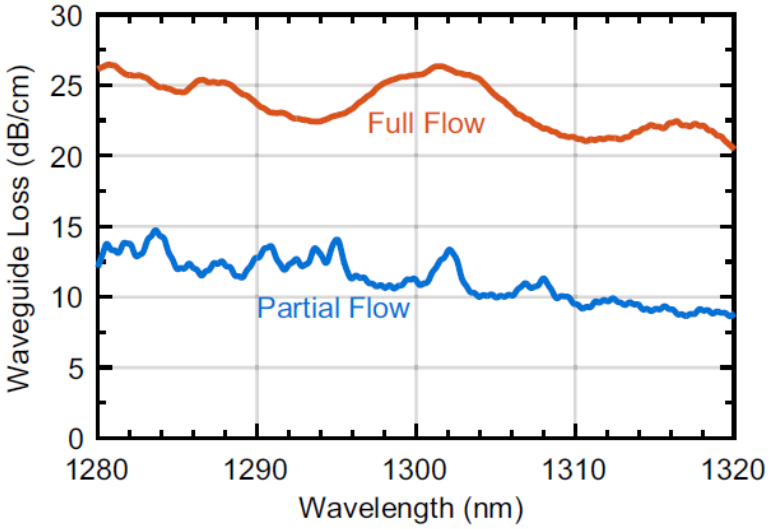
Alloatti et al., IET Optoelectronics **9(4)** (2015)



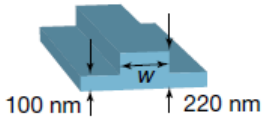
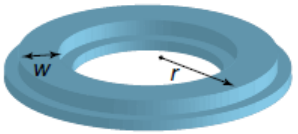
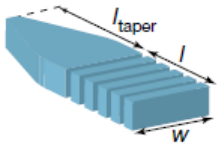
- Layout of the reticle performed in Cadence (Virtuoso Suite)
- Process design kits used: GF 10lpe + custom PDK for photonics
- In-house extension of Cadence Virtuoso to allow for solving DRC sizing issues (min feature size)
- No optical proximity correction employed
- Final layout on a non-Manhattan grid for processing file volume reasons

Passive components

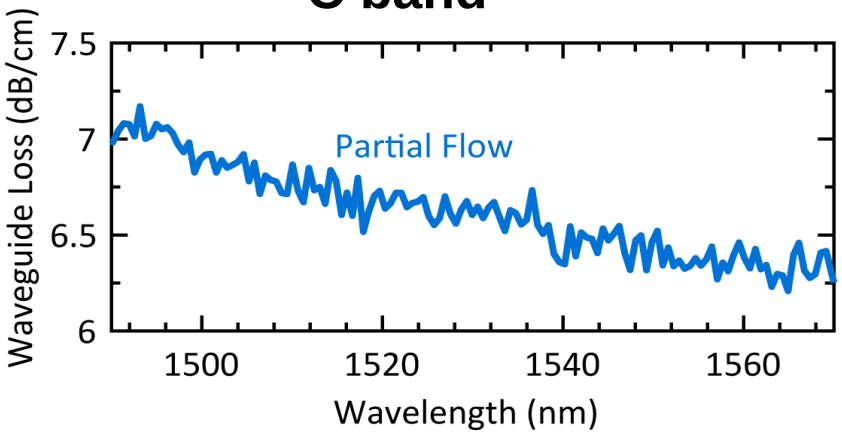
O band

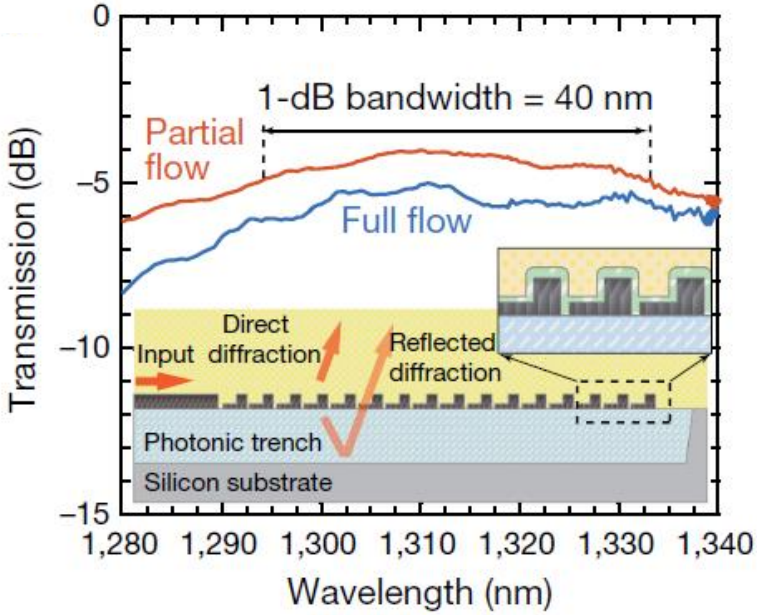


Passive components (specifications at 1,300 nm)

	Ridge waveguide	Ridge microring	Grating coupler
			
	Propagation loss	Intrinsic Q	Coupling loss
Partial flow	8–15 dB cm^{-1}	19,000–31,000	4.2 dB
Full flow	21–27 dB cm^{-1}	10,000–19,000	5.2 dB
Dimensions	w = 400 nm	w = 400 nm r = 7.5 µm	$w = l$ = 8 µm l_{taper} = 250 µm

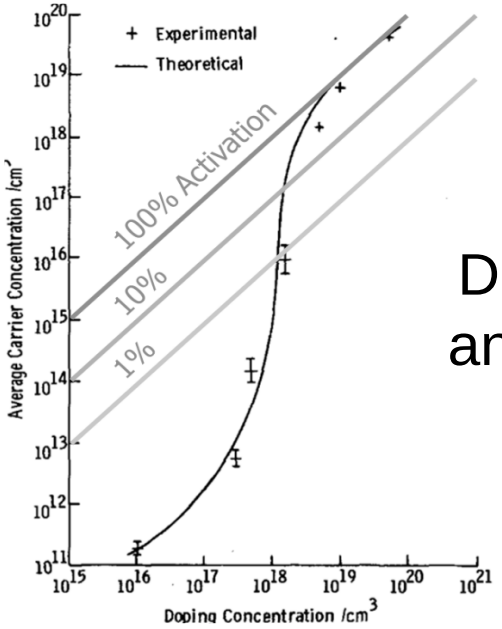
C band





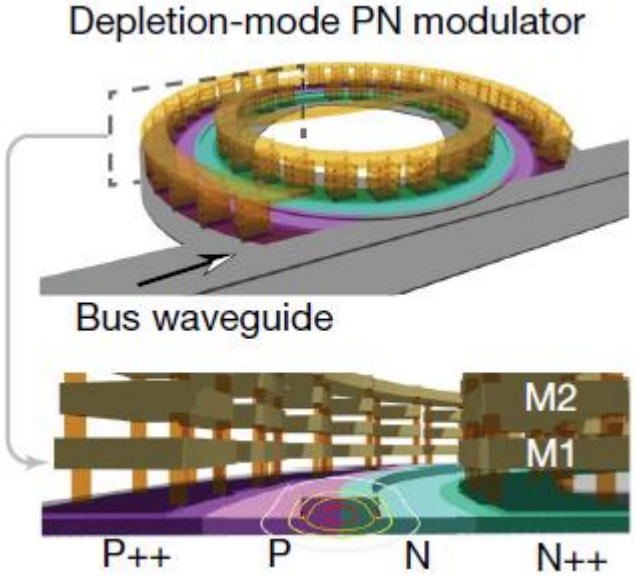
Atabaki, Moazeni, Pavanello et al., Nature 556, 2018.

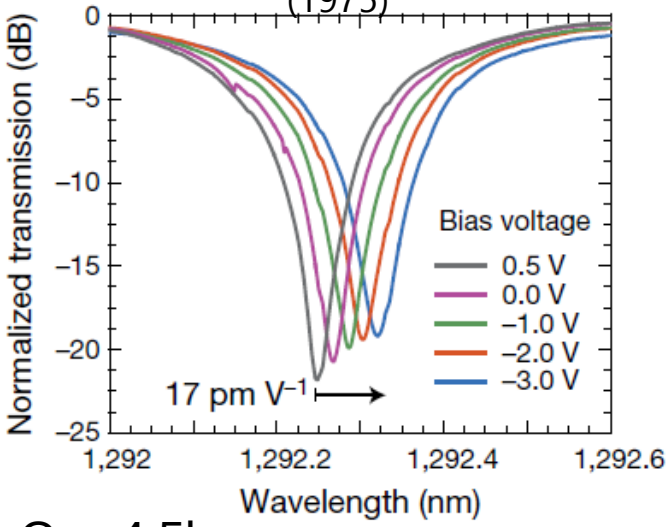
Active components: modulators

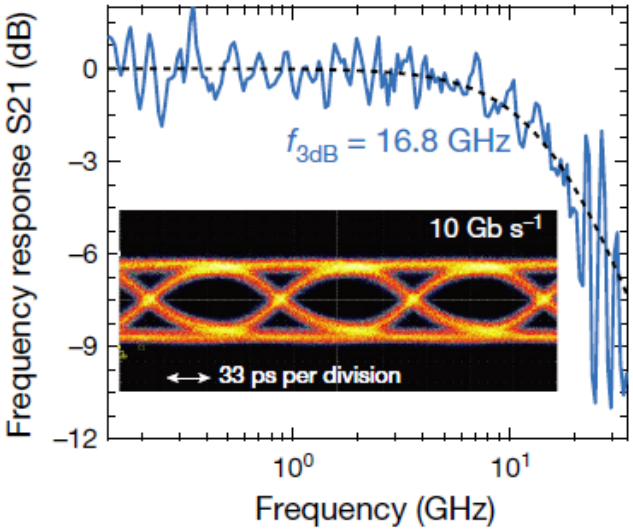


Seto et al., Appl. Phys. Lett. 46 (1975)

Deposition, annealing and implant conditions are critical!





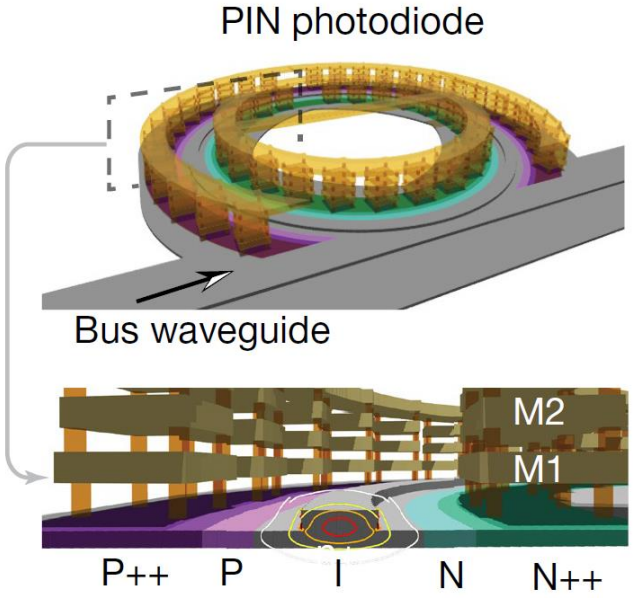


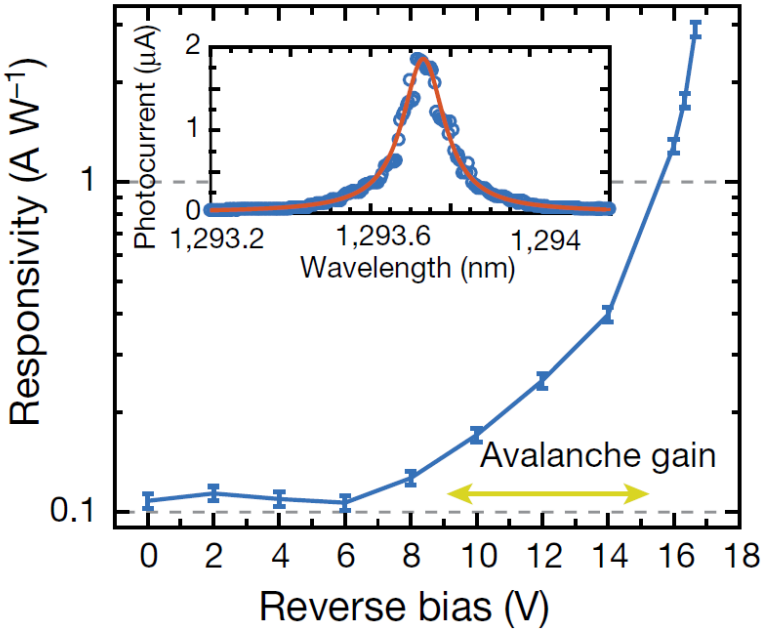
- 2 Vpp
- BW: 17 GHz
- ER: 5.7 dB
- IL: 3.8 dB

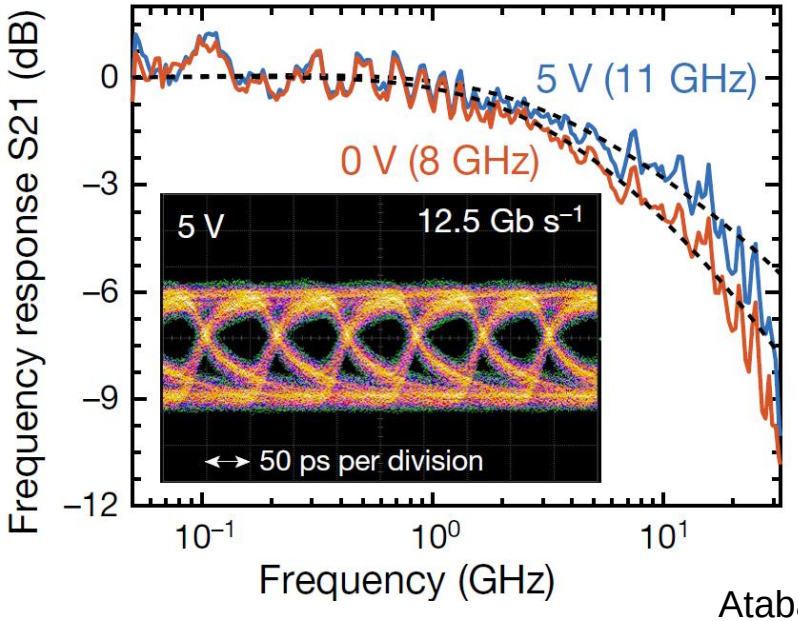
Q_l = 4.5k

Atabaki, Moazeni, Pavanello et al., Nature 556, 2018.

Active components: detectors



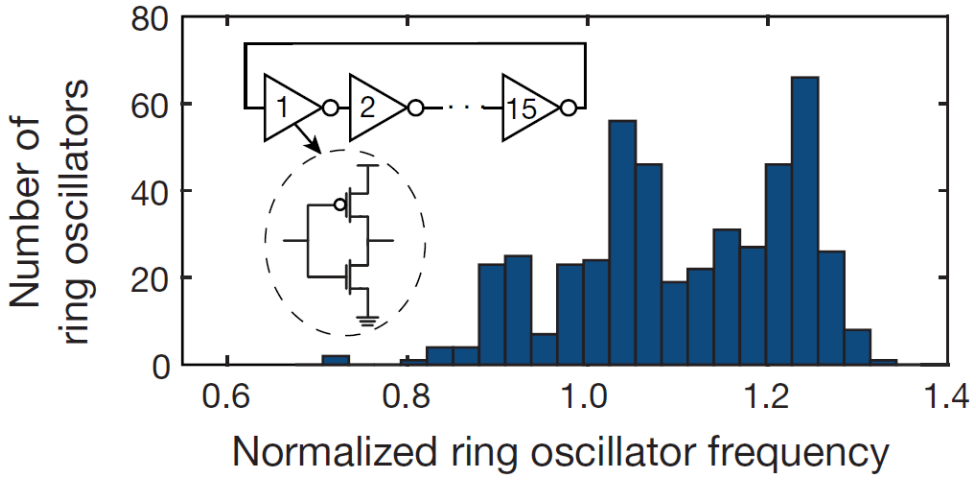




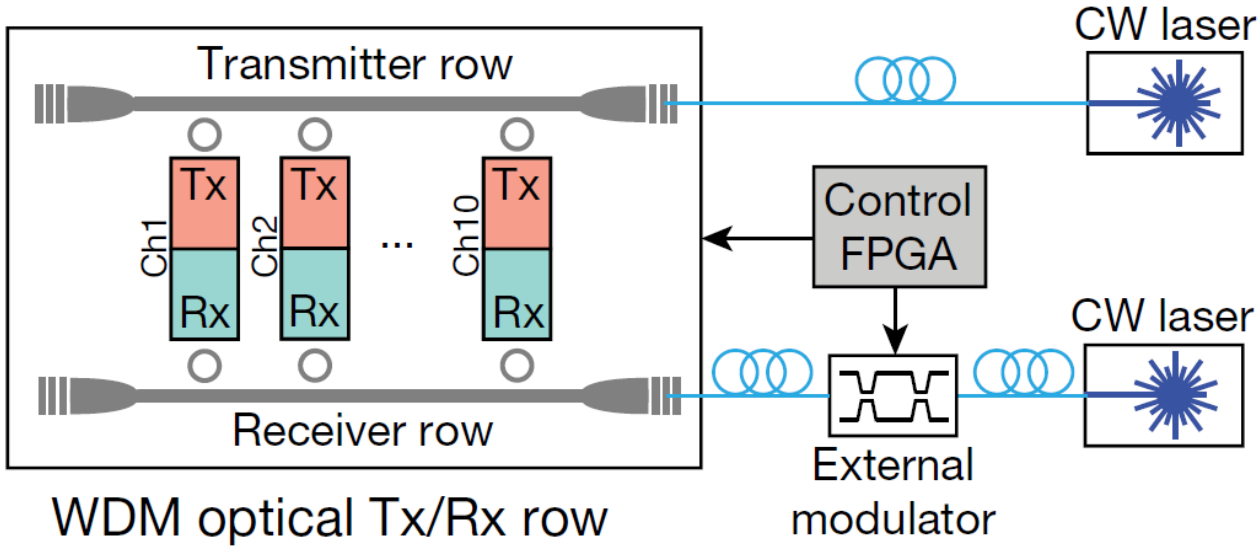
- Defect-mediated absorption
- BW: 8 (11) GHz @ 0 (5) V bias
- Avalanche gain: 13 @ 16 V bias

Atabaki, Moazeni, Pavanello et al., Nature 556, 2018.

O-Band Monolithic Photonic Transceivers

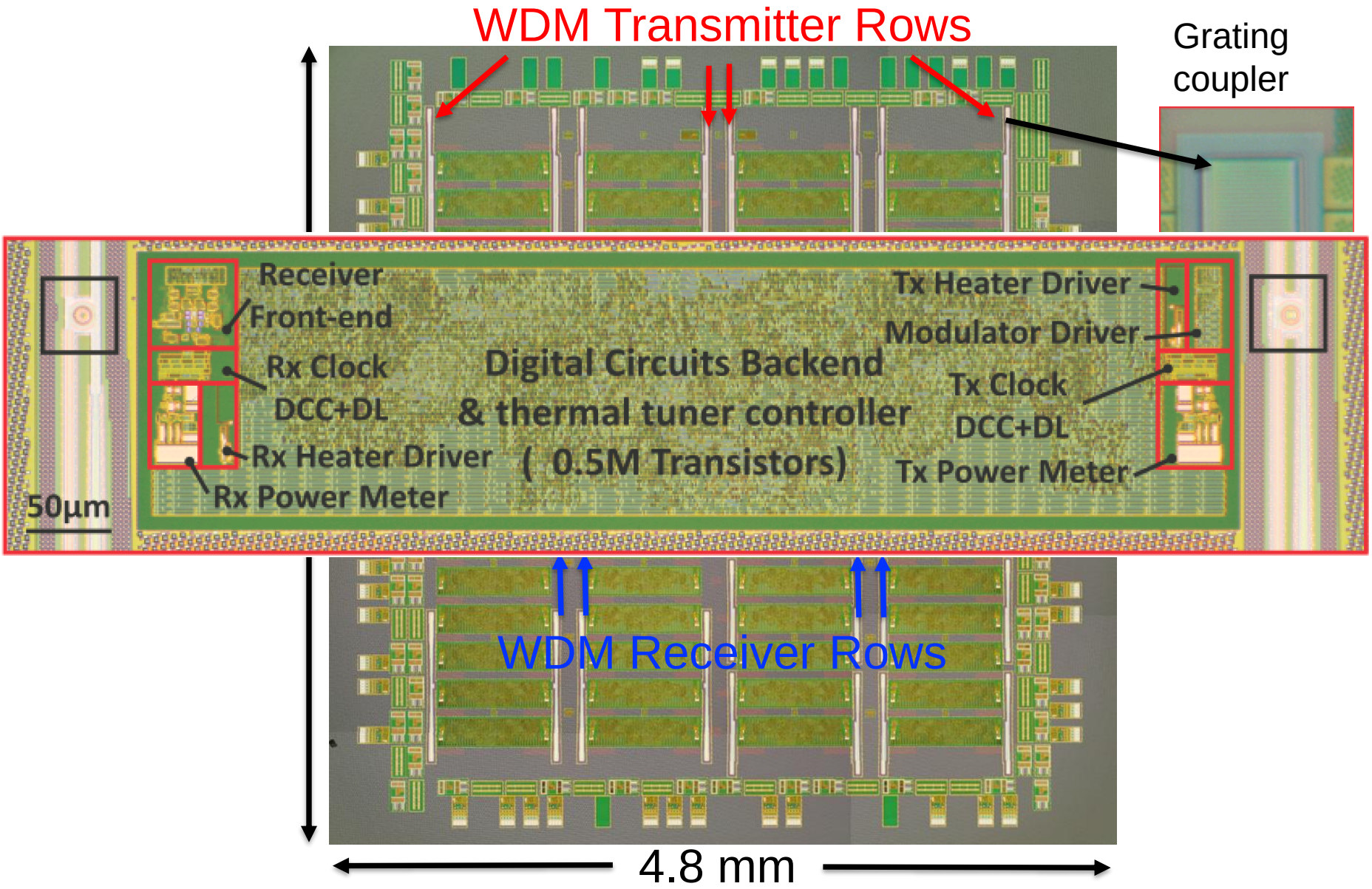


- Transistors performance are **not** compromised by the photonics module

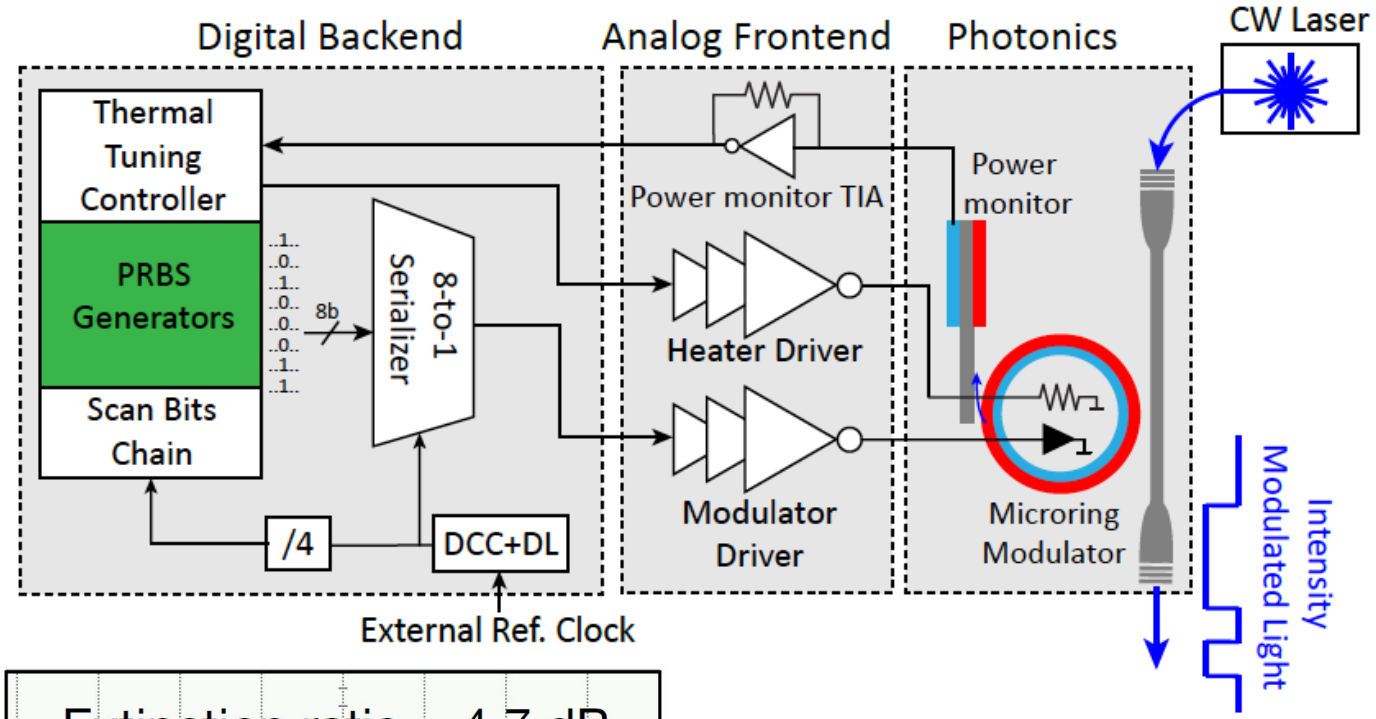


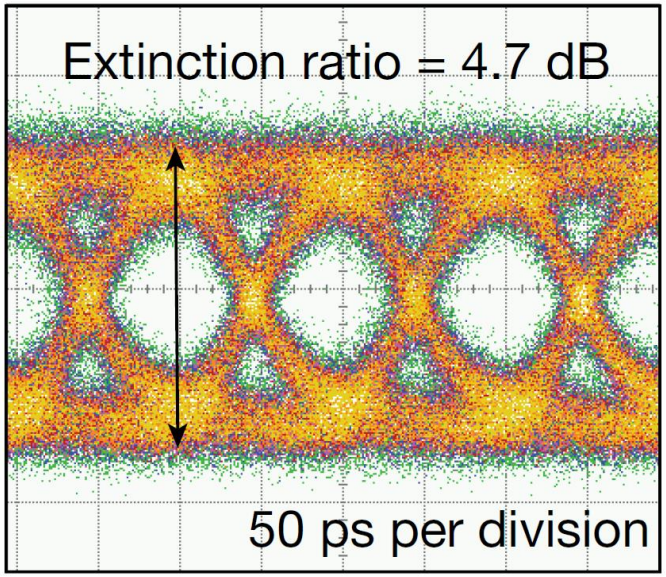
Atabaki, Moazeni, Pavanello et al., Nature 556, 2018.

Monolithic WDM Optical Transceivers



O-Band Monolithic Photonic Transmitter

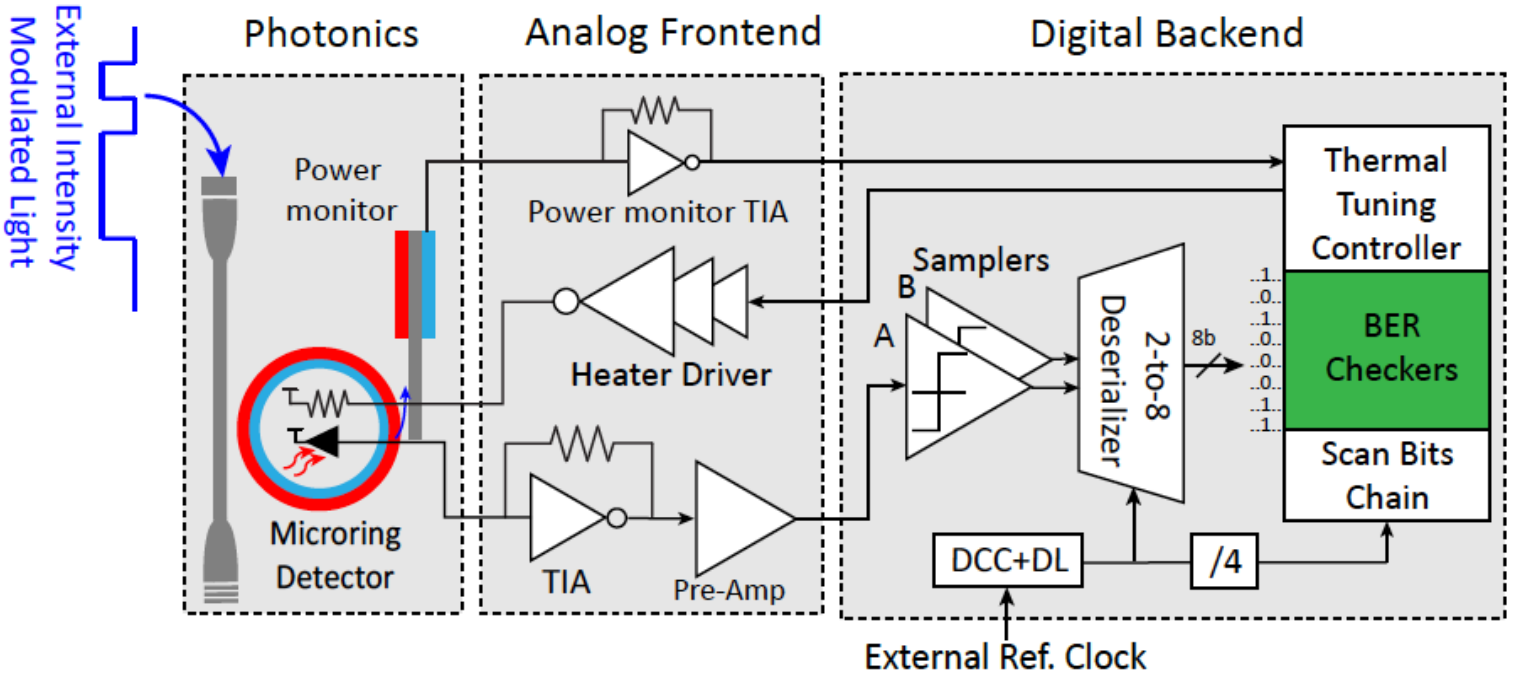


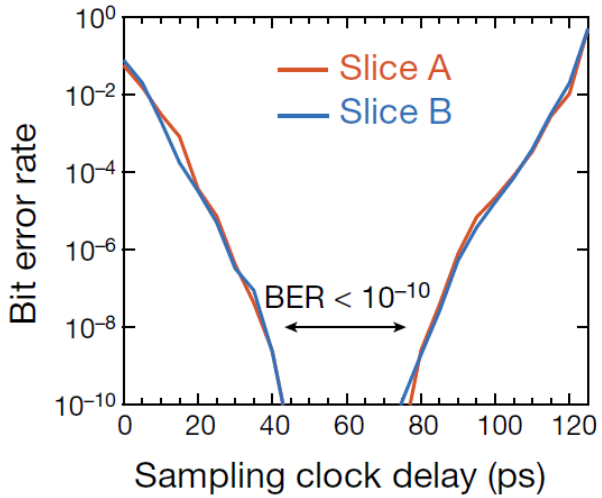


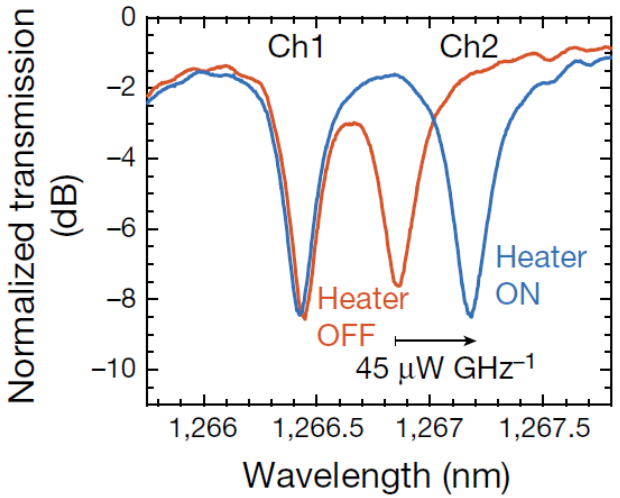
- 10 Gbit/s speed (limited by the circuits)
- 100 fJ/bit energy

Atabaki, Moazeni, Pavanello et al., Nature 556, 2018.

O-Band Monolithic Photonic Receiver







- 7 Gbit/s speed
- 500 fJ/bit energy
- Transceiver BW density: 180 Gb/s/mm^2

Atabaki, Moazeni, Pavanello et al., Nature 556, 2018.

Conclusions

- Polysilicon photonics as a viable material platform
- Integration of polysilicon photonics with deeply scaled CMOS
- 10 Gb/s monolithic transceivers demonstrated, 25 Gb/s is achievable with device optimizations
- Sub pJ/bit high bandwidth density transceiver: toward multi-Tbps I/O for CMOS chips

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