



Highly efficient nanophotonic devices on an InP membrane

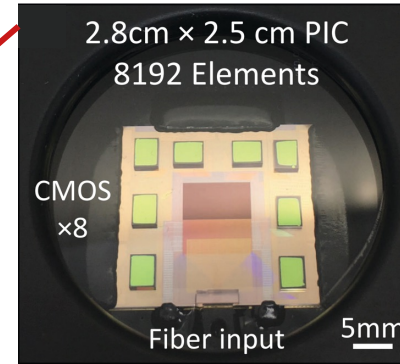
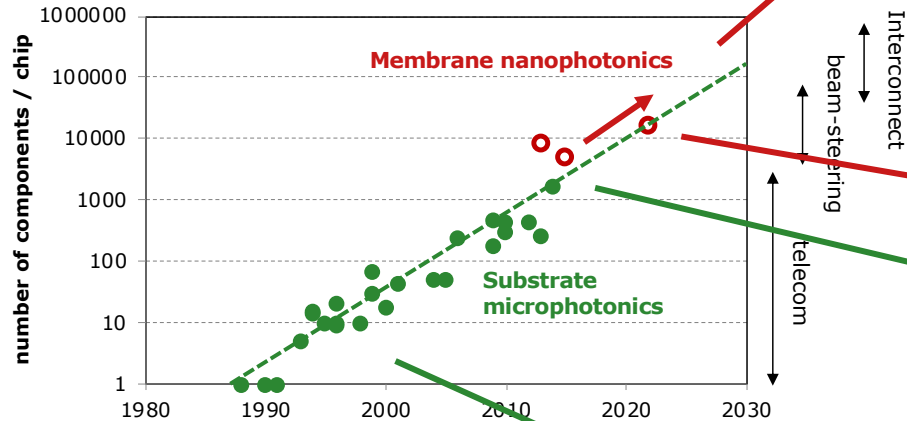
dr. Yuqing Jiao

Electrical Engineering, Photonic Integration

Outline

- Miniaturization in photonic integrated circuits
- Our technology on an InP membrane
- Recent demonstrations
- Summary

Photonic Integration

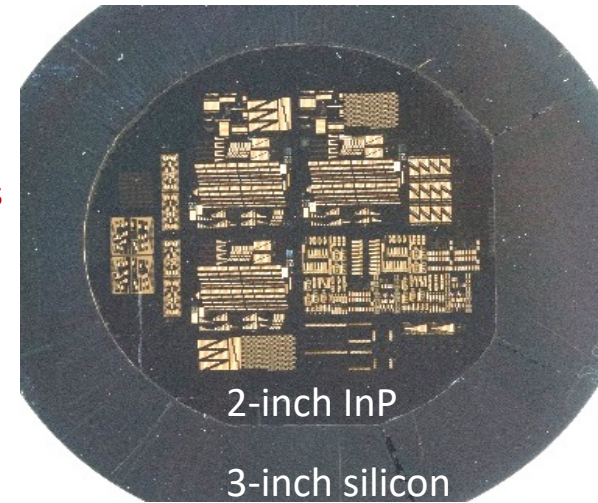
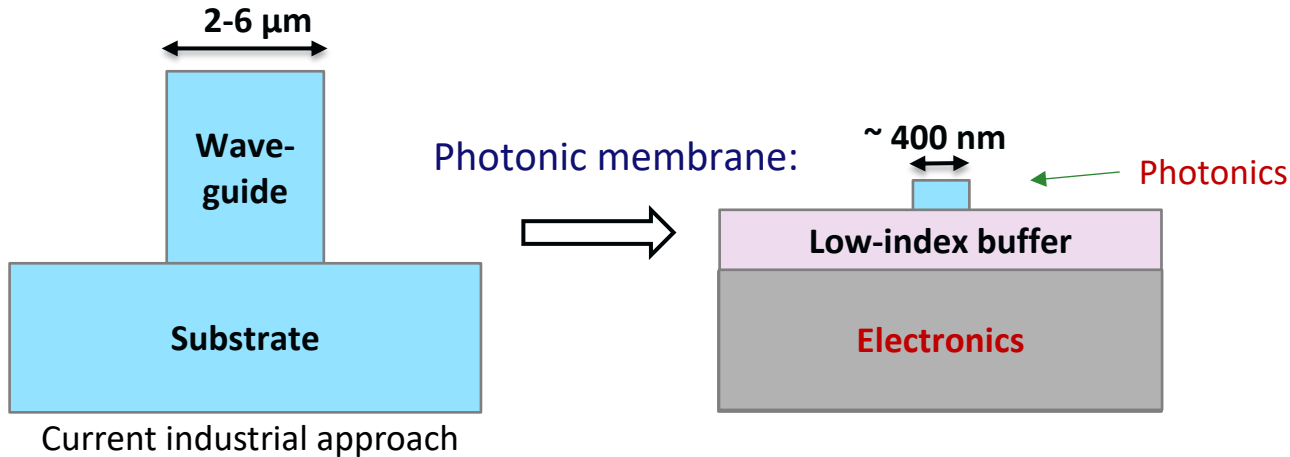


Optical phased arrays, neuromorphic network, etc
1000s-10,000s components

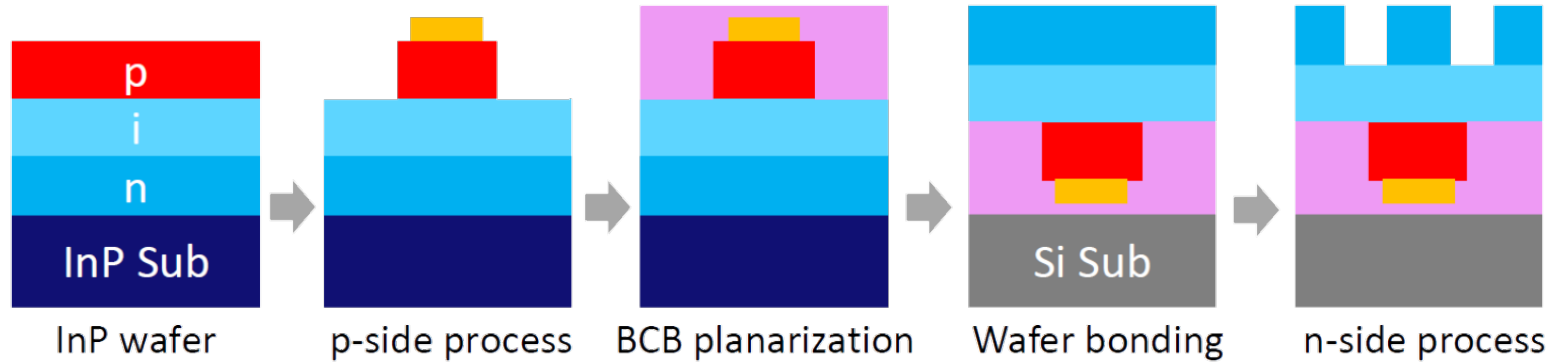


Photonic Integration in a membrane

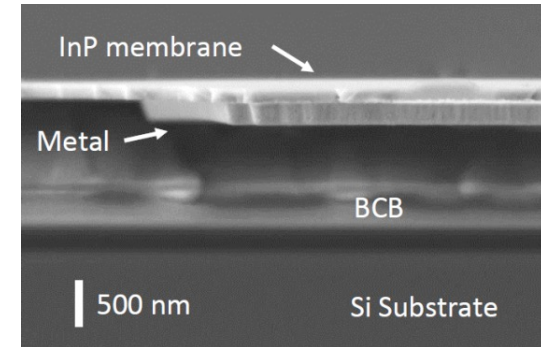
- Conventional InP technology face bottlenecks in density: they are too big
- InP membrane: InP amplifiers/lasers + SiPh-like nanowire waveguides
- Potential of wafer-scale assembly with electronics



Double-sided processing

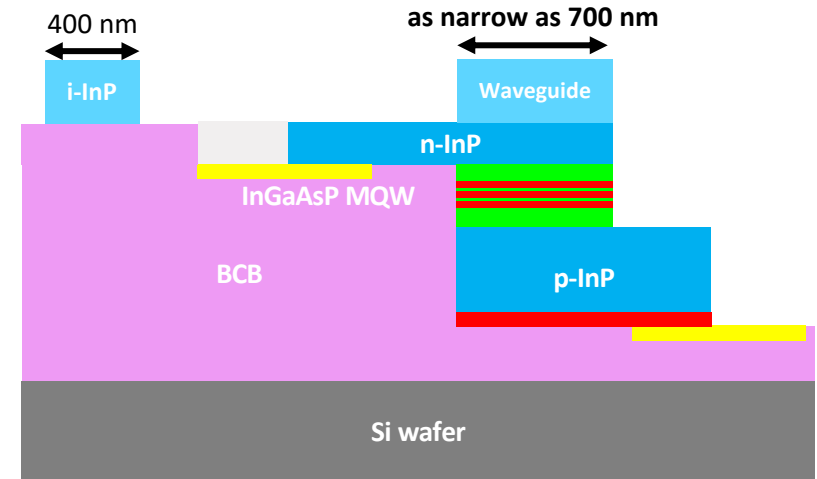
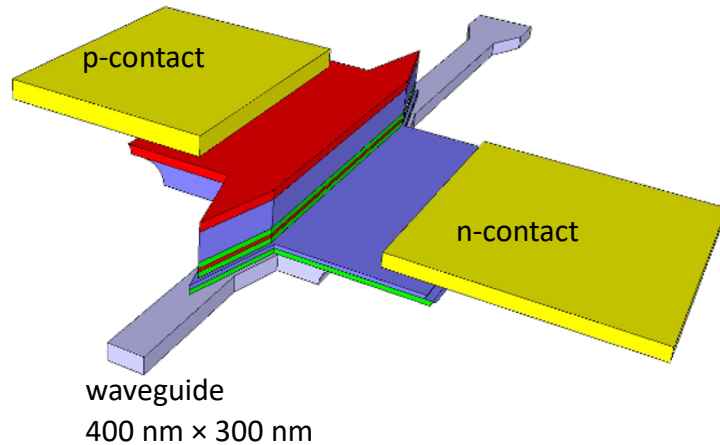


- x2 times ultra-flat surfaces for DUV Scanner lithography
- Design freedom for optimal optical and electrical performances



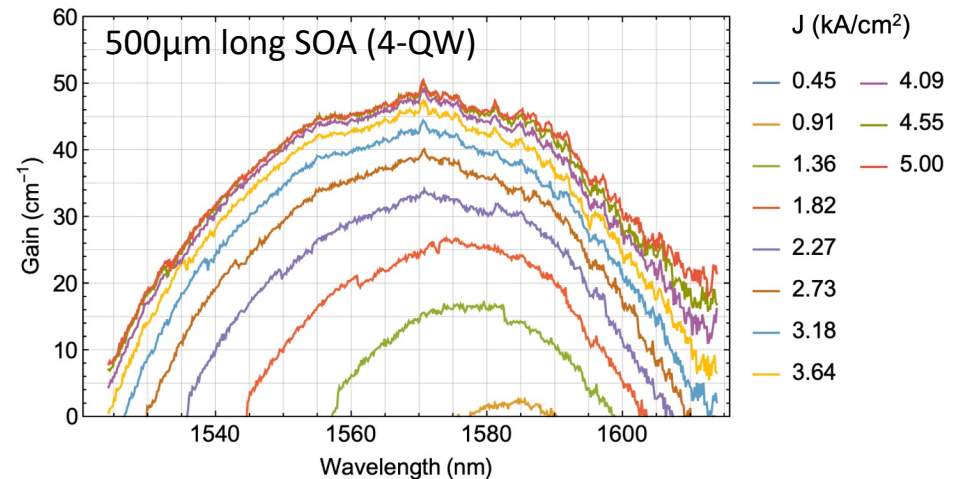
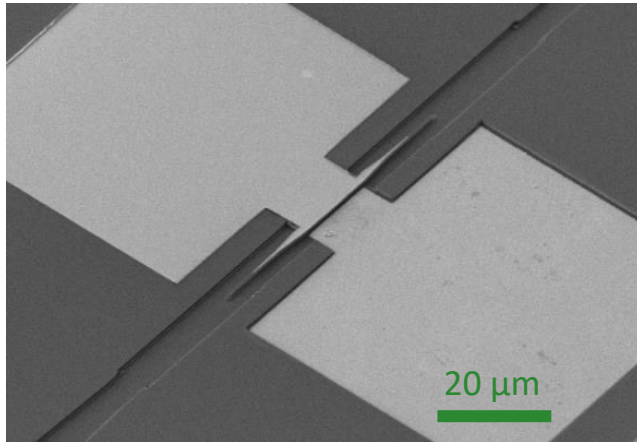
Lasers on nanophotonic waveguides

- S-shaped amplifier/laser for balanced confinement vs power handling
- Improve optical mode matching – very short tapers
- No critical alignment (lithography overlay accuracy)



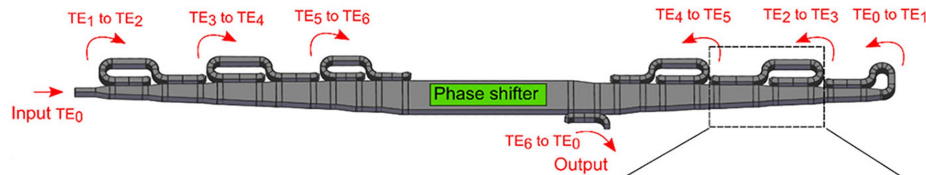
Membrane amplifier

- ~ 200 dB/cm net modal gain in 4-QW SOAs
- Essential building block for building lasers: DFB, DBR, tunable, etc¹.
- Tapers are active, can be solved by regrowth or QW intermixing



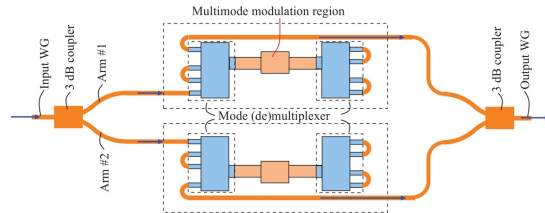
Mode multiplexing in Integrated Photonics

- Non-resonant light recirculation has been used to boost efficiency in linear optical devices
- Thermo-optic phase shifter

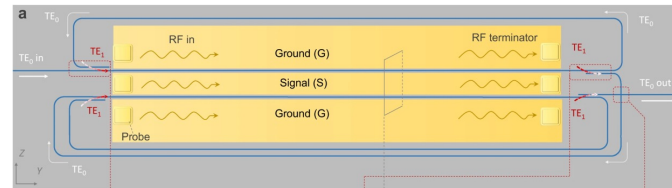


Optica 7, 3-6 (2020)

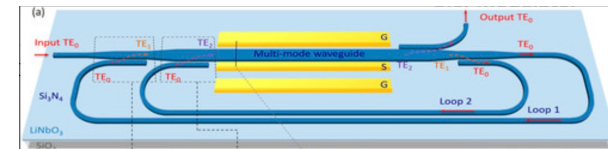
- And electro-optic phase shifters,



J. Semicond. 39 061009 (2018)



Communications Physics 6: 17 (2023)

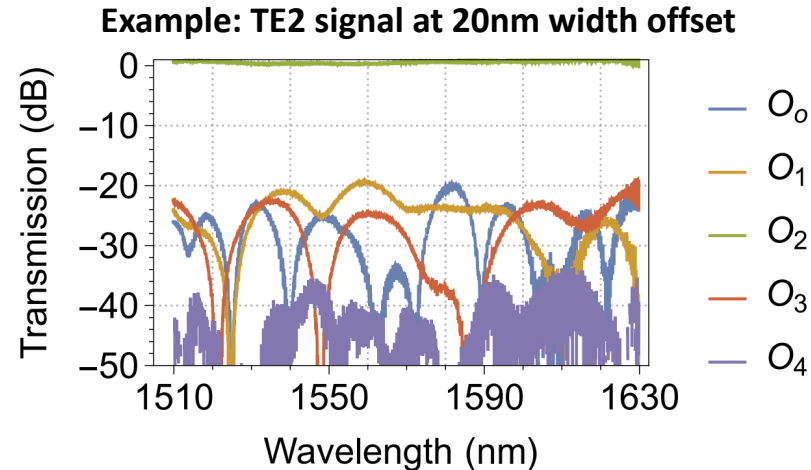
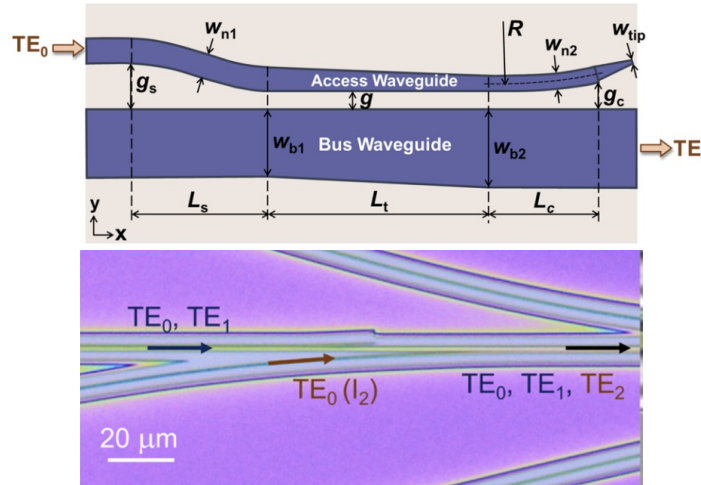


APL Photonics 7, 106102 (2022)

- Its use in nonlinear devices (SOAs, EAMs) is not studied: investigated for first time in this work

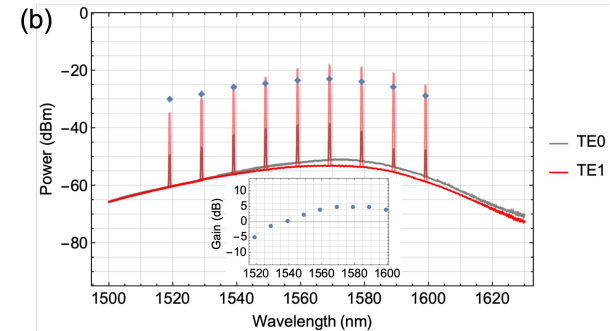
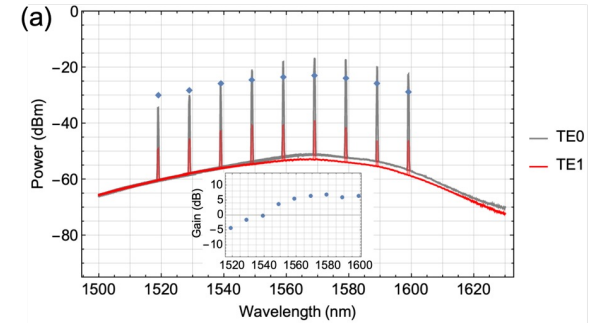
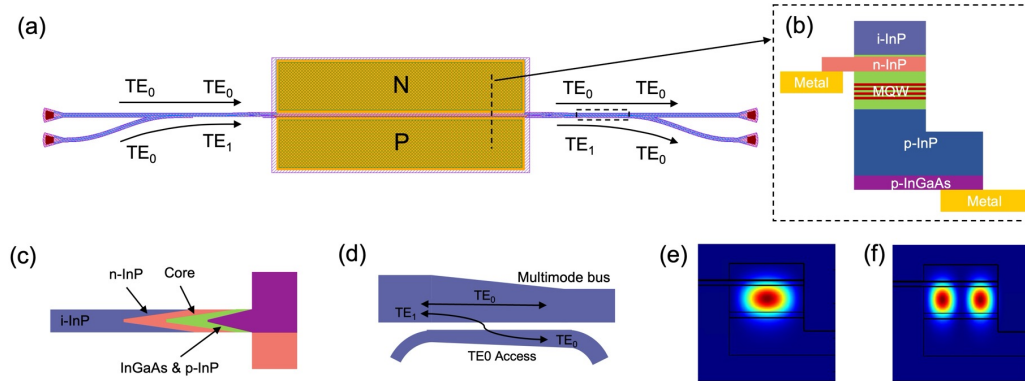
Fab tolerant mode (de)multiplexers in InP membrane

- First mode multiplexer (5 modes) on InP
- Broadband ($\sim 100\text{nm}$)
- $\text{EL} < 1\text{ dB}$, $\text{XT} < -14\text{ dB}$ with 50nm width variation (highest reported)
- Compared to Si, InP offers higher fab tolerance due to moderate index contrast



Mode multiplexing in membrane SOAs

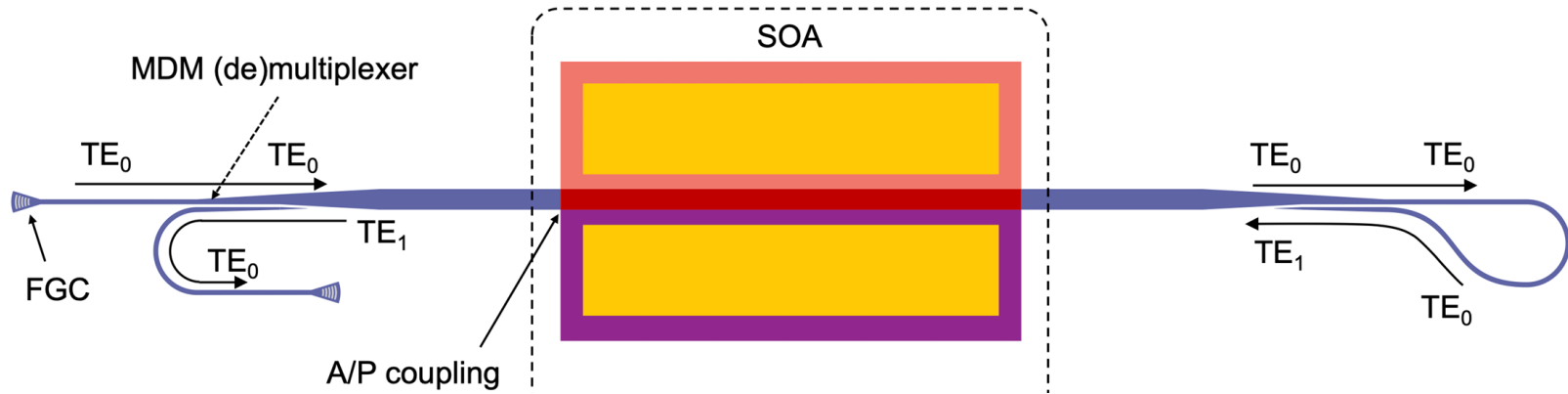
- Combining mode multiplexers and amplifiers made possible InP membrane technology
- TE_1 experiences slightly lower gain than TE_0
- Use TE_1 to harvest “leftover” carriers from TE_0



Boosting efficiency of SOAs

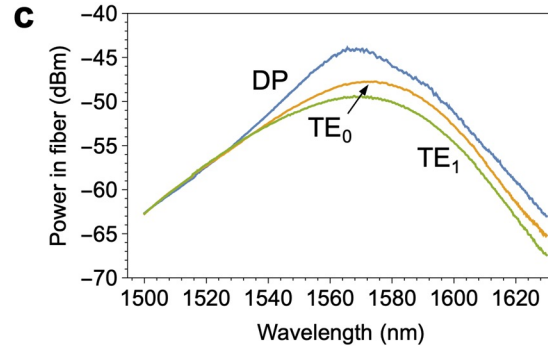
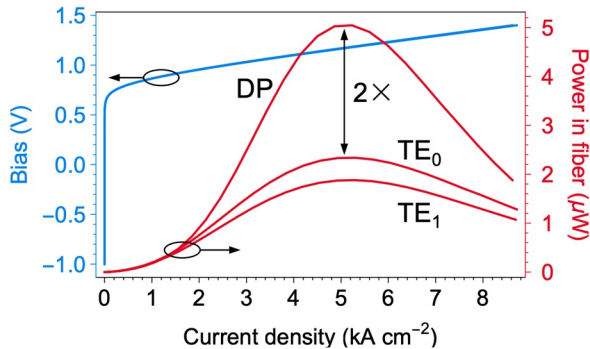
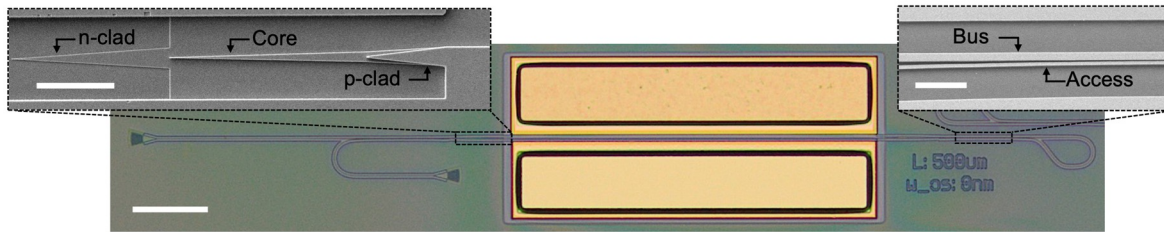
Non-resonant 2-pass SOAs based on mode multiplexing:

- Low-crosstalk in the MDM coupler suppresses resonance;
- Harvesting unused to obtain:
- Gain boosted without increase in pump current, and/or
- “Halved” footprint and pumped energy for the same gain.



Boosting efficiency of SOAs

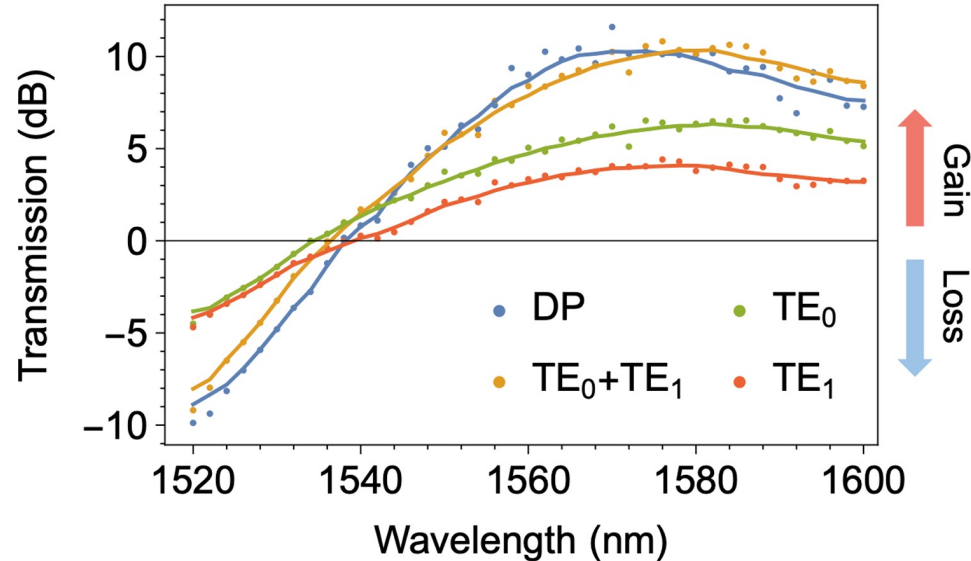
2-pass amplified spontaneous emission:



Boosting efficiency of SOAs

2-pass net modal gain (500um long SOA at 4.1 kA/cm²):

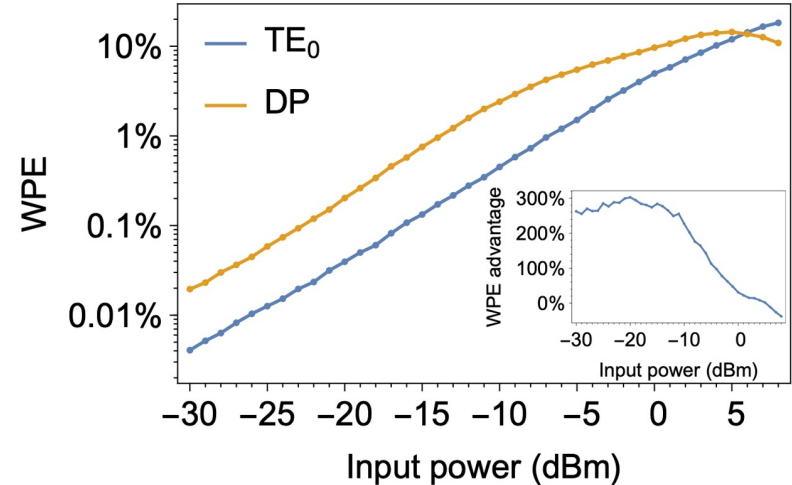
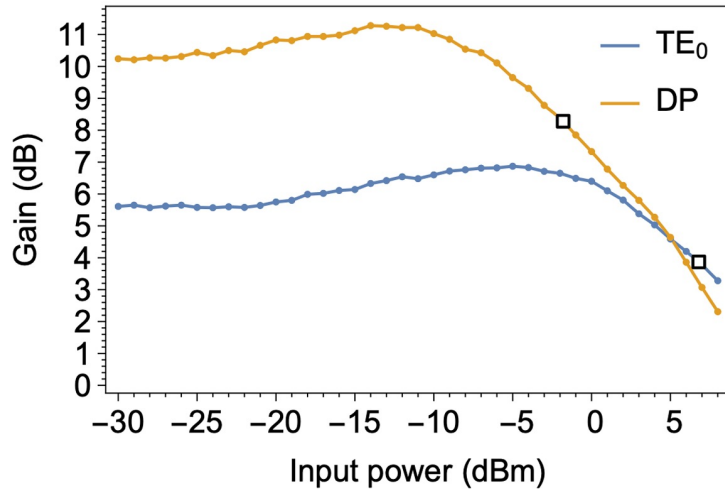
- Gain boosted from 6.2 dB for single pass to 11.6 dB (87% enhancement)
- Wall-plug efficiency (300% enhancement)
- Absorption (as EAM) also boosted as seen in 1520-1540nm region



Boosting efficiency of SOAs

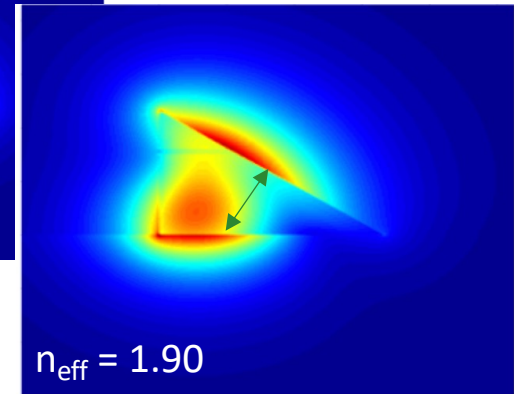
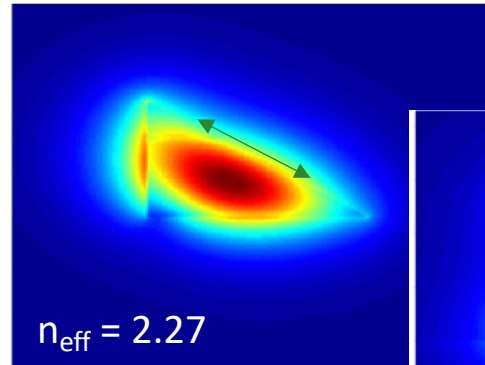
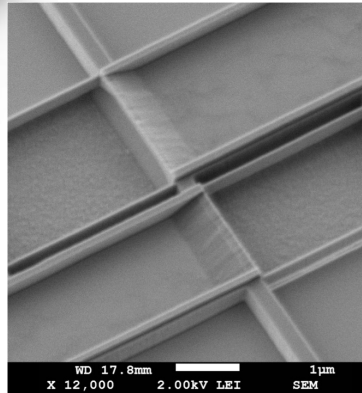
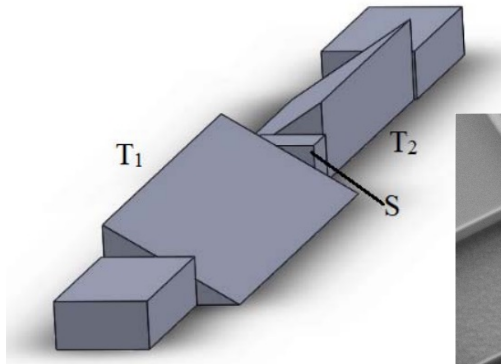
Saturation is earlier for 2-pass than 1-pass;

Significant advantage for low input powers (which is the case for most telecom, datacom and switching applications)



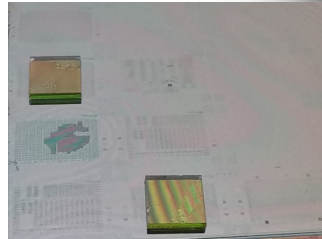
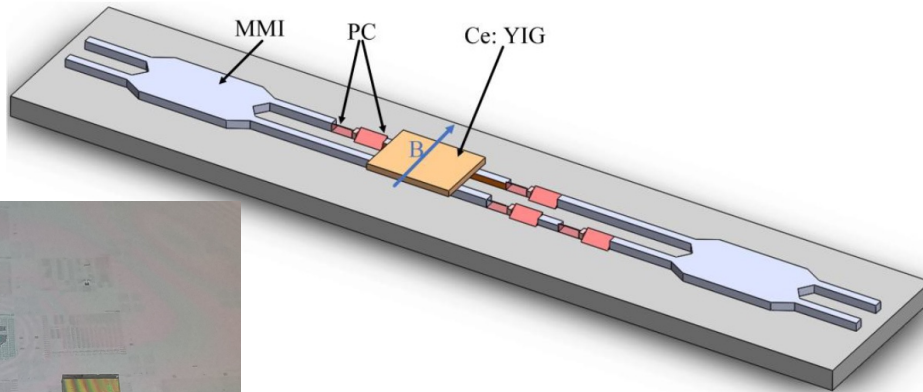
Ultracompact polarization controller

- Triangular waveguide for extremely efficient polarization rotation
- High fabrication precision by exploiting natural “slow-etch” crystal plane
- Full TE/TM conversion (16 dB extinction) within **4 μm** length (record small)

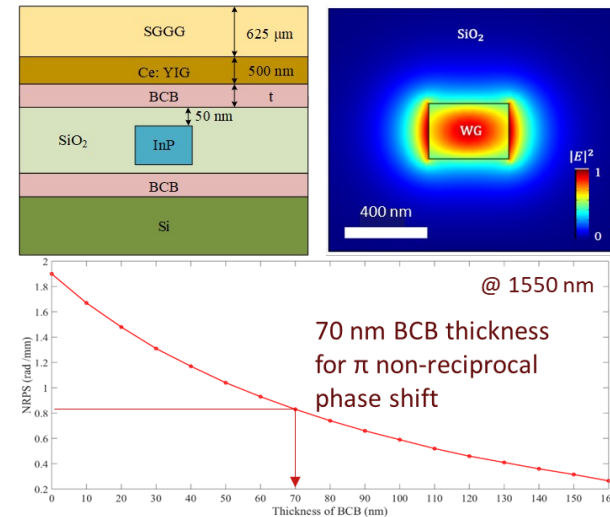


Integrated isolator/circulator

- First on-chip isolator on InP PICs (up to 34 dB isolation demonstrated)
- Direct integration right next to the InP lasers
- Novel polarization insensitive design utilizing ultracompact polarization controller

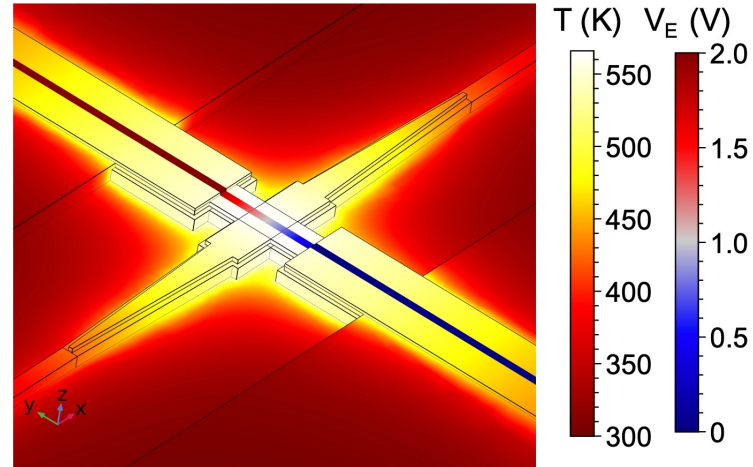
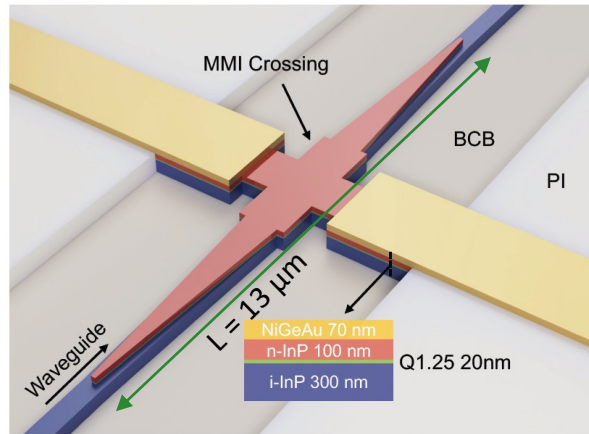


Provisional EU Patent No. 2028831
Optica vol. 8, pp. 1654-1661, 2021.
Journal of Quantum electronics, accepted, 2023



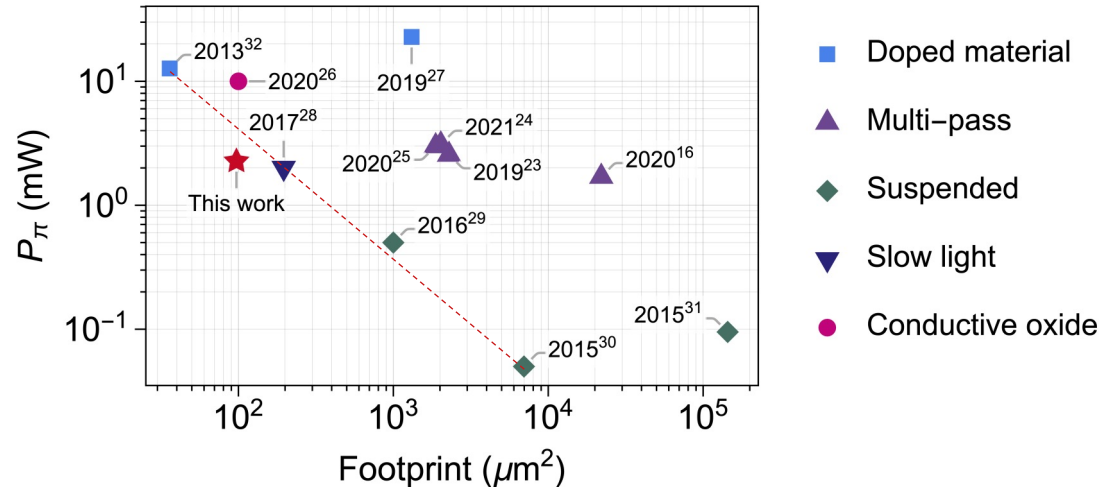
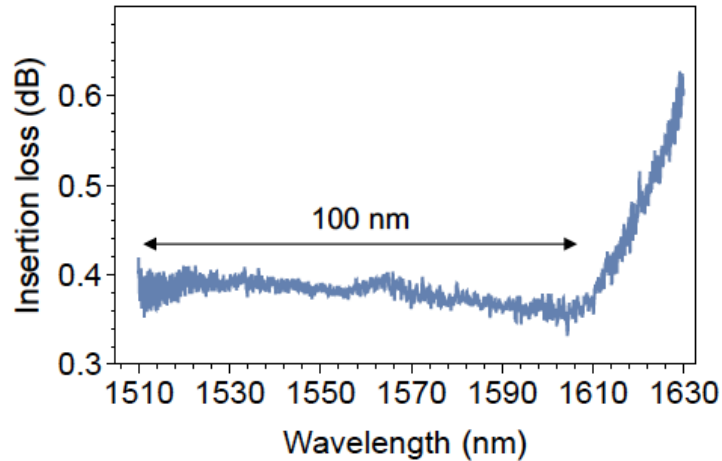
Ultracompact phase shifters

- Native n-InP conductive layer for efficient heating
- MMI-crossing structure for minimal optical loss
- Footprint < 100 μm^2 , including metal tracks



Ultracompact phase shifters

- Broadband 100 nm with low loss < 0.4 dB
- Tuning efficiency 2.26 mW/ π ; competitive figure of merit $P_\pi * Area$
- InP has higher thermo-optic coefficient than Si -> theoretical 20% less power consumption



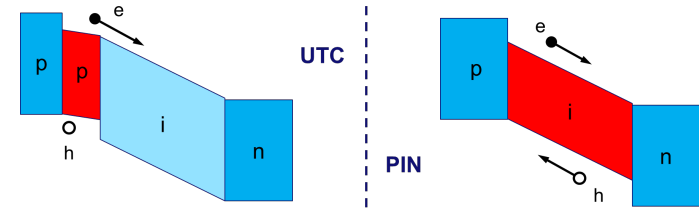
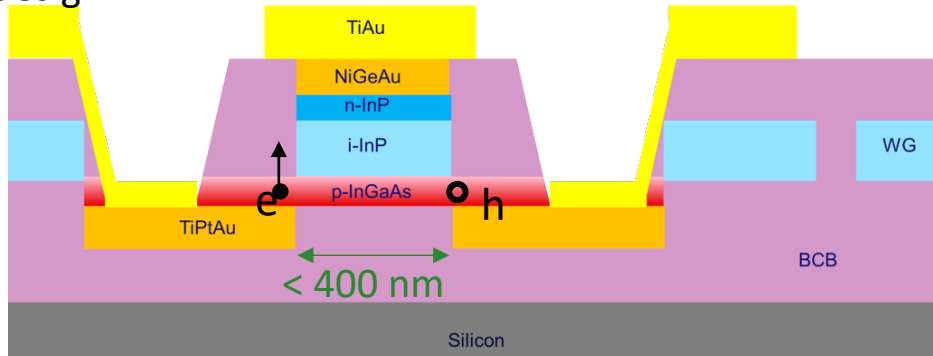
>110 GHz photodiode

- Enabled by double-sided design and processing

Conventional design



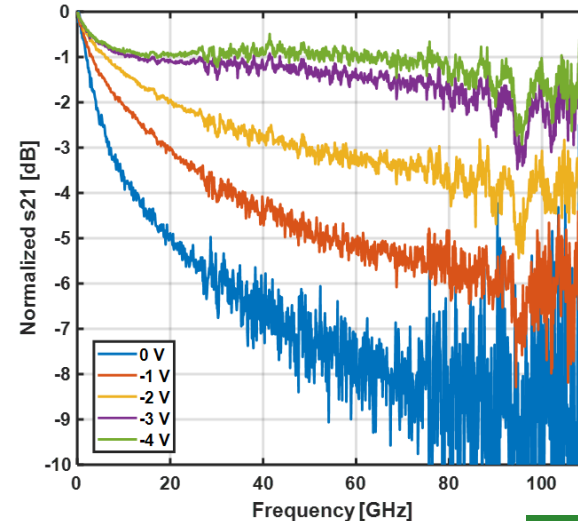
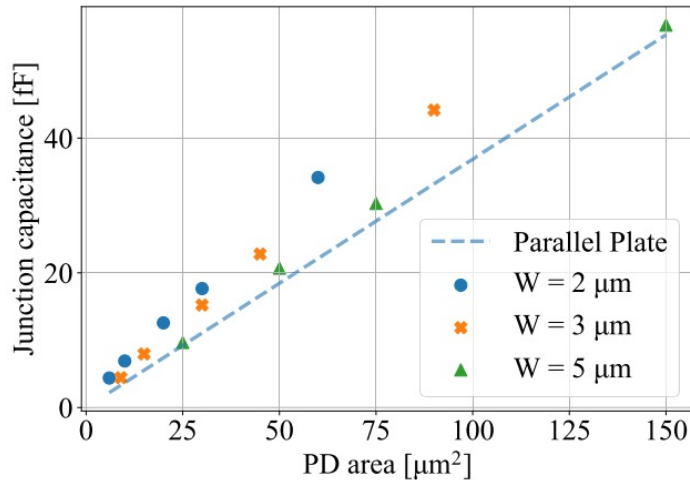
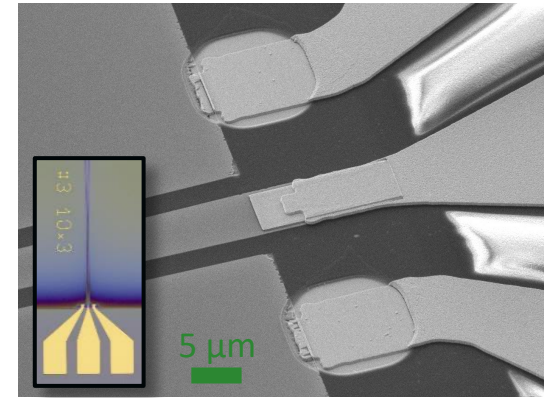
Our design



- Uni-traveling-carrier (UTC) design
- Closer metal contacts without loss compromise

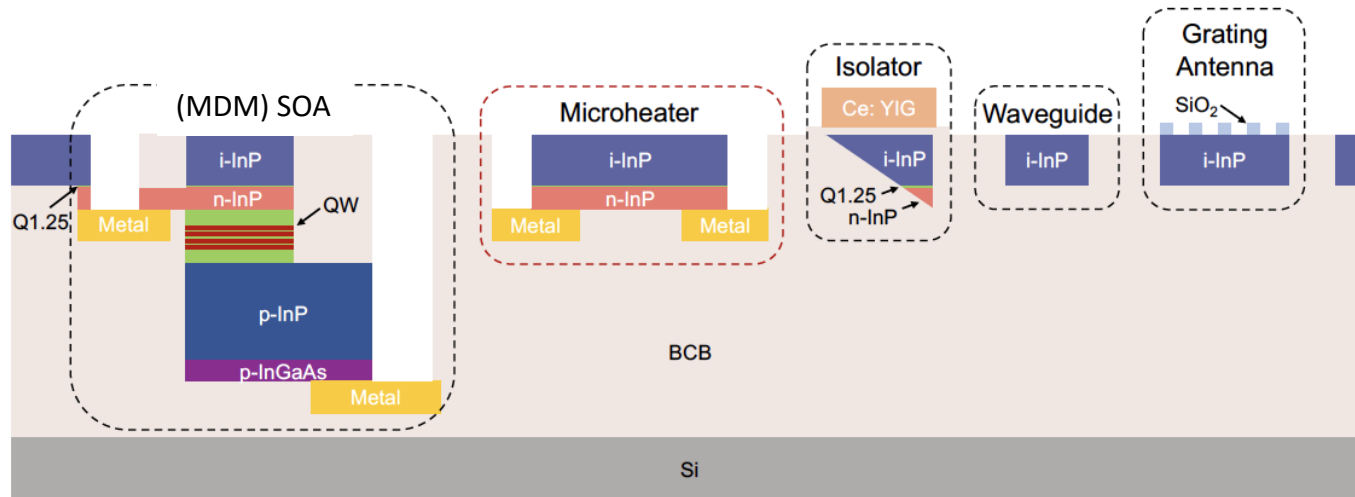
>110 GHz photodiode

- Internal Responsivity: 0.75 A/W ($5\mu\text{m} \times 2\mu\text{m}$)
- Bandwidth: > 110 GHz
- Ultralow capacitance 4 fF & Series resistance < 10 Ω



Laser and nanophotonics in one process flow

- An active-passive platform realized with a single process flow
- Re-use part of SOA layers for heaters and polarization controllers
- Eliminate the need of assembly or bonding for external light source



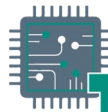
Summary

- Active-passive photonic integration on an InP membrane
- InP membrane nanophotonics enables compact and highly efficient devices for gain, absorption, polarization rotation and phase shifts
- Towards a complete integration platform for high-density applications



Gravitation

Thanks you for your attention!



TWILIGHT



PHOTONICS PUBLIC PRIVATE PARTNERSHIP

PHOTONICS²¹

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