School of Engineering & Applied Science
THE GEORGE WASHINGTON UNIVERSITY

OPEN LAB

Breaking the Boundary between Optical Communication and Data Processing

Shuai Sun[1], *Vikram Narayana*[1,2], *Richard Soref*[3], *Hamed Dalir*[4], *Tarek El-Ghazawi*[1], *Volker Sorger*[1]
[1]George Washington University, [2]Intel Corp., [3]University of Massachusetts, [4]Omega Optics Inc.

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH · UNITED STATES AIR FORCE
NSF
SBIR America's Seed Fund POWERED BY DOT

Communication

HyPPI: Interconnect Option

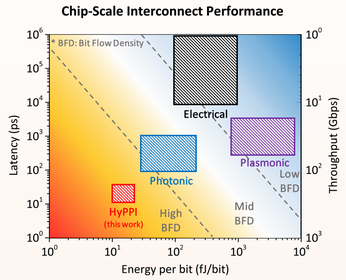
Photonics (Signal Propagation)
- ☒ Diffraction Limited
- ☒ Large Footprint
- ☒ Low LMI
- ☑ Long Propagation

+

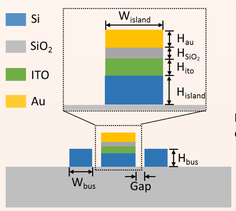
Plasmonics (Signal Manipulation)
- ☑ No Diffraction Limit
- ☑ Area Efficient
- ☑ Energy Efficient
- ☒ Short Propagation

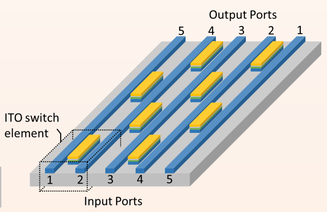
- ✓ 10-100× Energy Efficiency
- ✓ 10-1000× Speed
- ✓ 10× Throughput
- ✓ 10-1000× Packing Density

HyPPI Improvements



O-Router: Hybrid Broadband Router



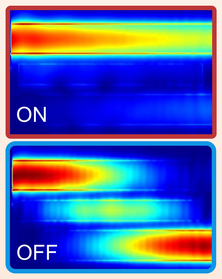


BAR
- ✓ V_{dd} = 4V
- ✓ 13 fJ/bit
- ✓ IL=2.1 dB
- ✓ ER=24.2 dB

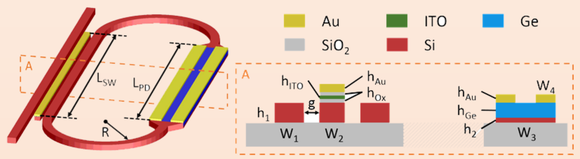
CROSS
- ✓ V_{dd} = 0V
- ✓ 0 fJ/bit
- ✓ IL=0.4 dB
- ✓ ER=9.3 dB

9μm · 195GHz · 100nm

HPP 2×2 Switch Performance



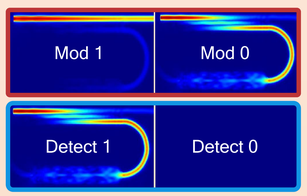
MODetector: Optical Transceiver



Modulator — Sending
- ✓ 106 GHz
- ✓ 4.5 μm²
- ✓ IL=1.2dB
- ✓ ER=16.6dB

Detector — Receiving
- ✓ 35 GHz
- ✓ 90 μm²
- ✓ 0.62 A/W
- ✓ I=0.31 mA

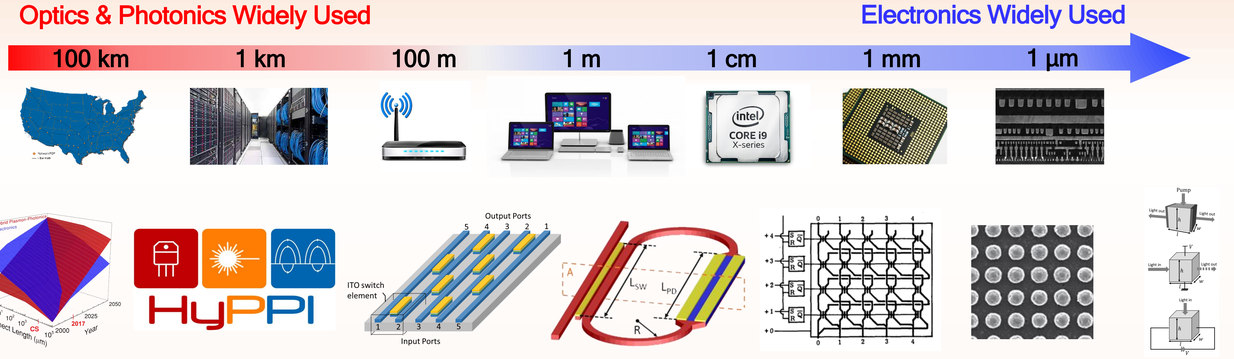
MODetector Performance



Motivation

Optics & Photonics Widely Used → Electronics Widely Used

100 km · 1 km · 100 m · 1 m · 1 cm · 1 mm · 1 μm

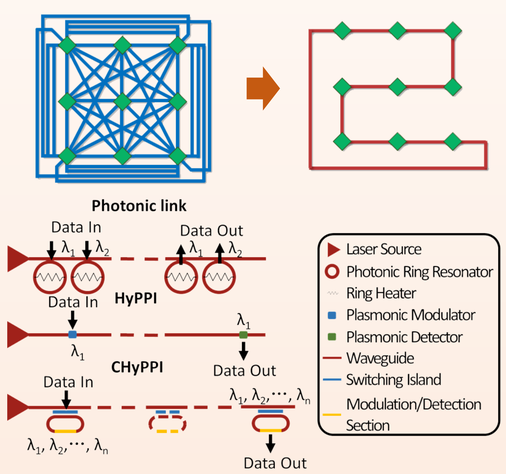


Breaking the Boundary

Integrating HPP Devices into Networks

- ✓ Simplify the network architecture
- ✓ Broadband over 100 nm
- ✓ Support WDM with multiple wavelength
- ✓ Each node is non-blocking
- ✓ No O-E-O conversions needed for routing

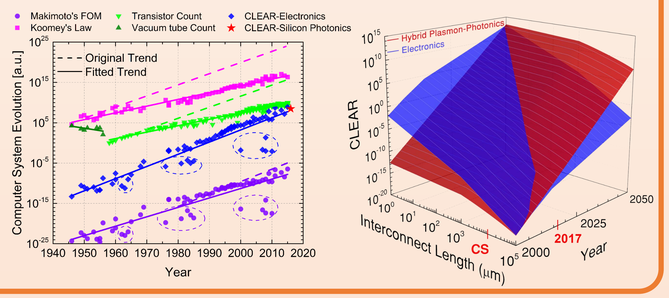
Device Integration



Holistic Evolution Figure of Merit

$$\text{CLEAR} = \frac{\text{Capability}}{\text{Latency} \times \text{Energy} \times \text{Amount} \times \text{Resistance}}$$

This universal metric termed Capability to Latency Energy Amount Resistance (CLEAR) is:
- a holistic set of performance parameters cover both physical and economic factors
- able to post- and predict the evolution rate
- valid among different technology cycles



Our Work

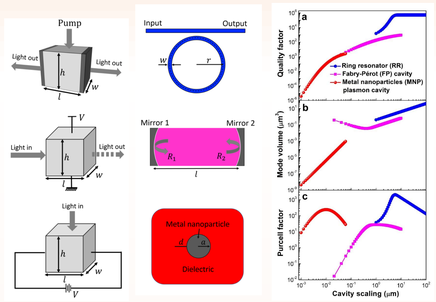
Papers (partial list)
- S. Sun, et al., ***Optics Express***. (accepted)
- J. Peng, S. Sun, et al., ***Optics Letters***. (under review)
- R. Wang, et al., ***Nanophotonics***. (under review)
- A. Mehrabian, S. Sun, et al., ***Computing Frontiers 2018***. (under review)
- S. Sun, et al., ***IEEE Spectrum*** . (under review)
- S. Sun, et al., ***IEEE Photonics Journal*** (2017).
- V. Narayana, S. Sun, et al., ***Microprocessors and Microsystems*** (2017).
- V. Narayana, S. Sun, et al., ***ICPP*** (2016).
- K. Liu, S. Sun, et al., ***Scientific Reports 6*** (2016).
- S. Sun, et al., ***IEEE Photonics Journal*** (2015).

Patents
- Hybrid Photonic Plasmonic Interconnects (HyPPI) with intrinsic and extrinsic modulation options
- Double Biased Hybrid Photonic-Plasmonic Broadband Switch based Non-blocking Optical Routing Design
- Reconfigurable Optical Co-processor
- MODetector: A Dual-Function Optical Modulator-Detector for On-Chip Communication (submitted)
- Residue Number System Arithmetic based on Integrated Nanophotonics (submitted)

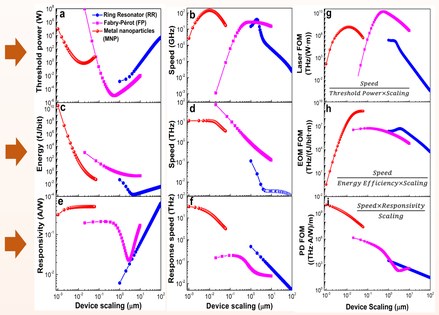
Computation

Fundamental Scaling: Building Laws

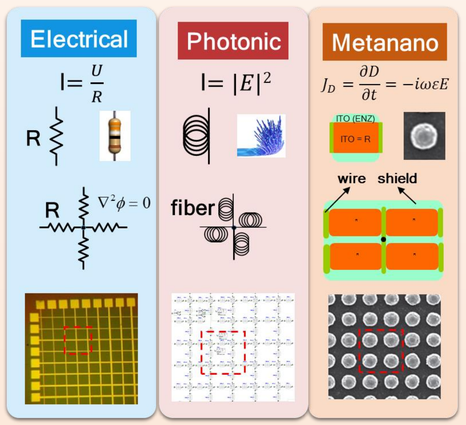
Ring Resonator · Fabry-Pérot · Metal Nanoparticle



Laser · Electro-optical Modulator · Photodetector



ROC: Reconfigurable PDE Solver



RNS: Adder and Multiplier

- ✓ Strict-sense non-blocking
- ✓ Broadband over 100 nm
- ✓ Only 10 switches needed for a 5×5 device
- ✓ 7 fJ/bit switching efficiency
- ✓ 202 μm² footprint
- ✓ 5.1 ps response time

RNS Adder & Multiplier