Electro-photonic Integrated Deep Learning Processor using Si Photonic Integrated Circuits

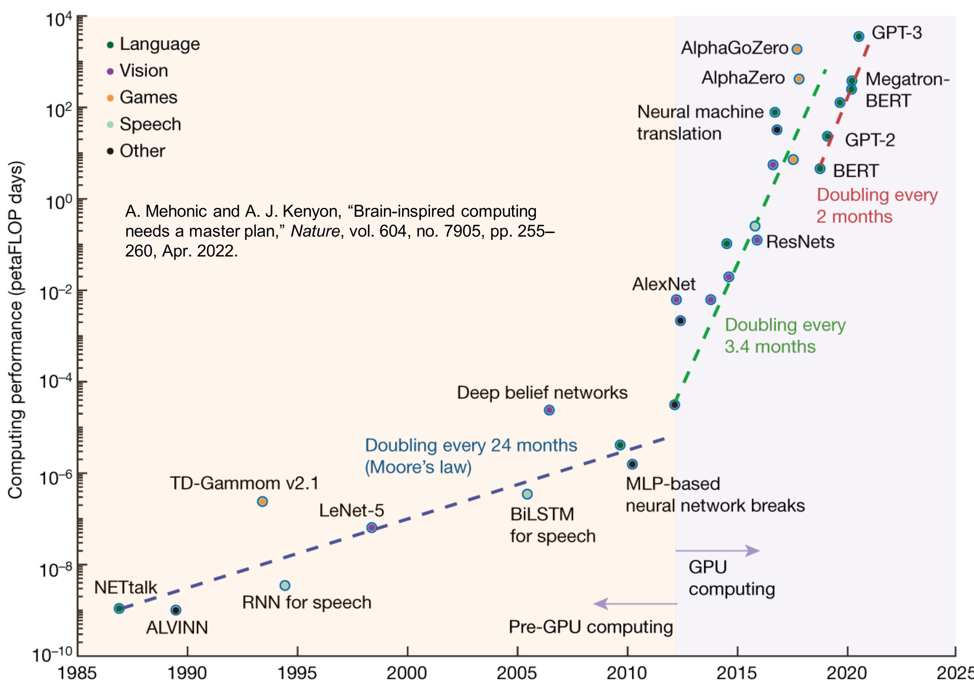
Mitsuru Takenaka, Professor

The University of Tokyo, Department of Electrical Engineering and Information Systems

7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

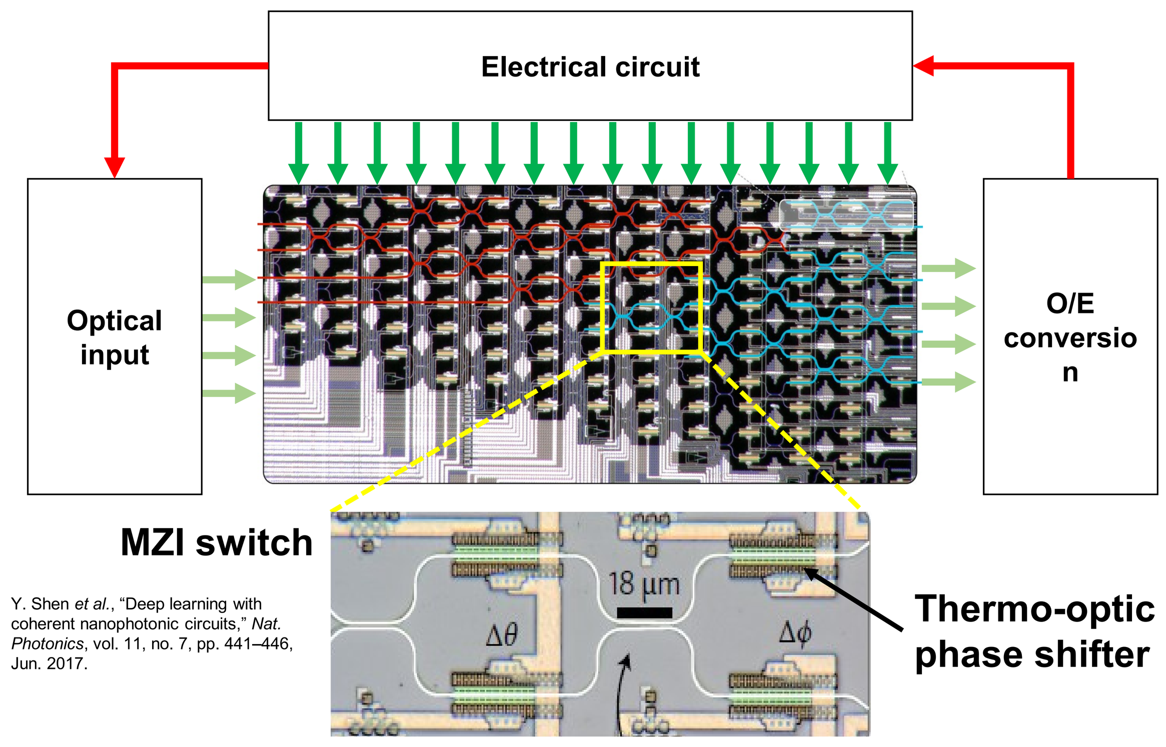
takenaka@mosfet.t-u-tokyo.ac.jp

1. Background



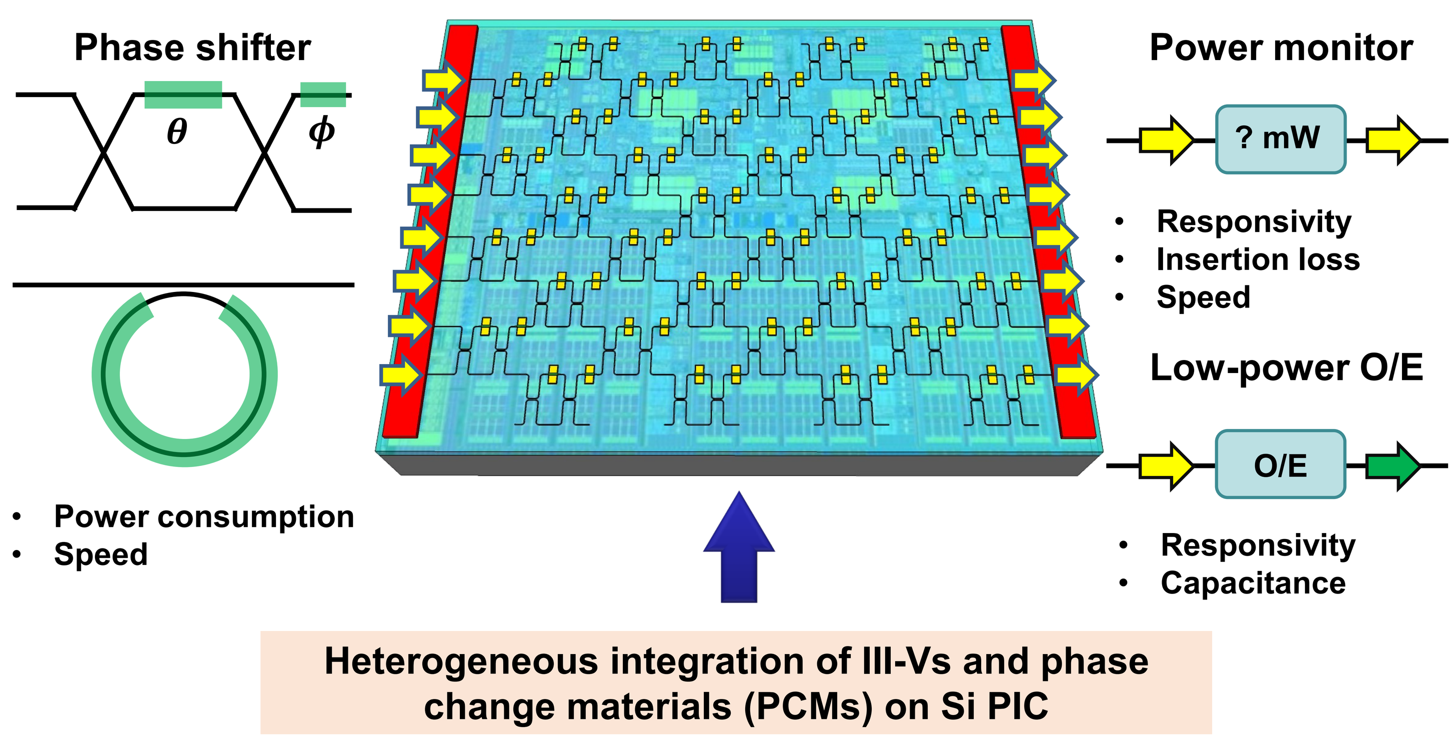
- The computing performance for generative AI is increasing at a rate that exceeds semiconductor miniaturization (Moore's Law).
- A new computing technology is essential for AI.

Deep learning processor based on Si programmable photonic integrated circuit

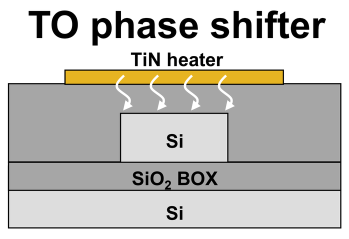


- MAC operation can be performed in the optical domain using Si programmable PIC.
- High-speed, low-power, low-latency computing is expected.

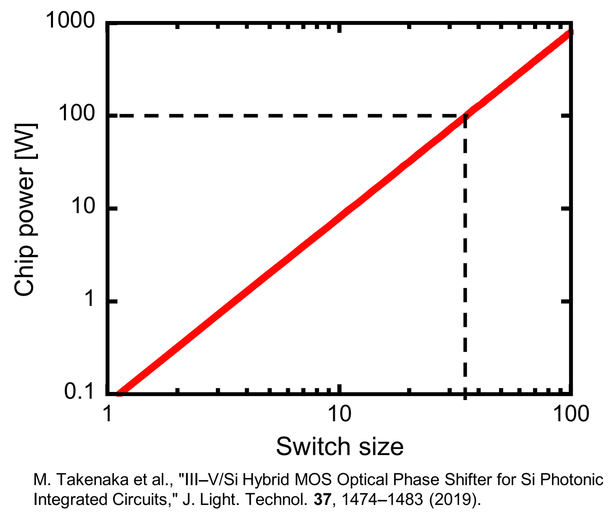
Technology issues of Si programmable PIC



2. Optical phase shifter

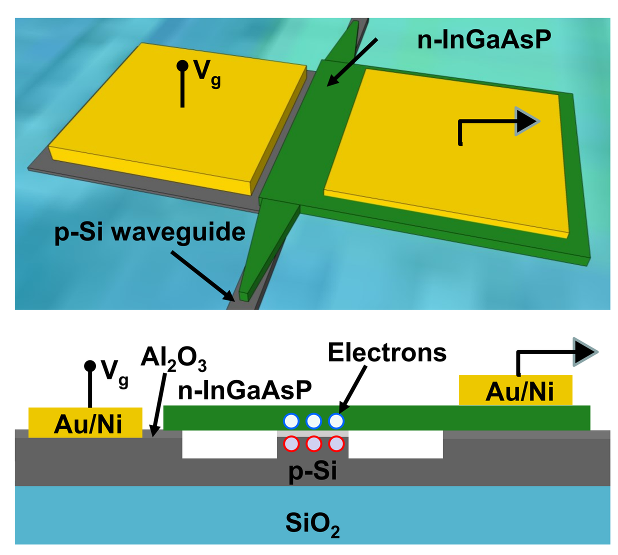


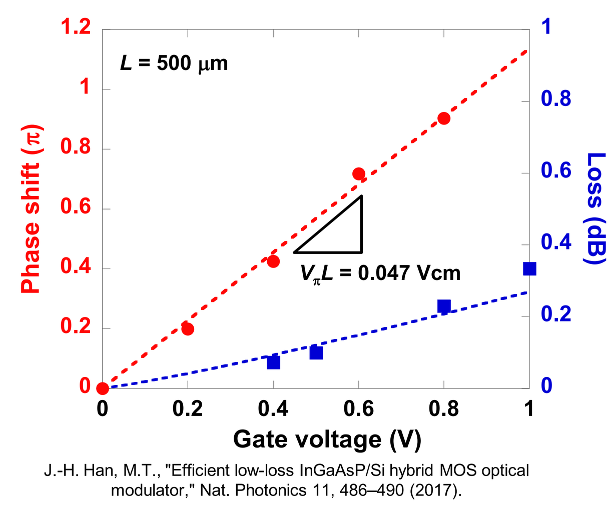
Power	20 mW
Thermal crosstalk	Large
Speed	> 20 μs
Loss	< 0.1 dB



- The power consumption of conventional thermo-optic (TO) phase shifter is too large for large-scale programmable PIC.
- Low-power optical phase shifter is essential.

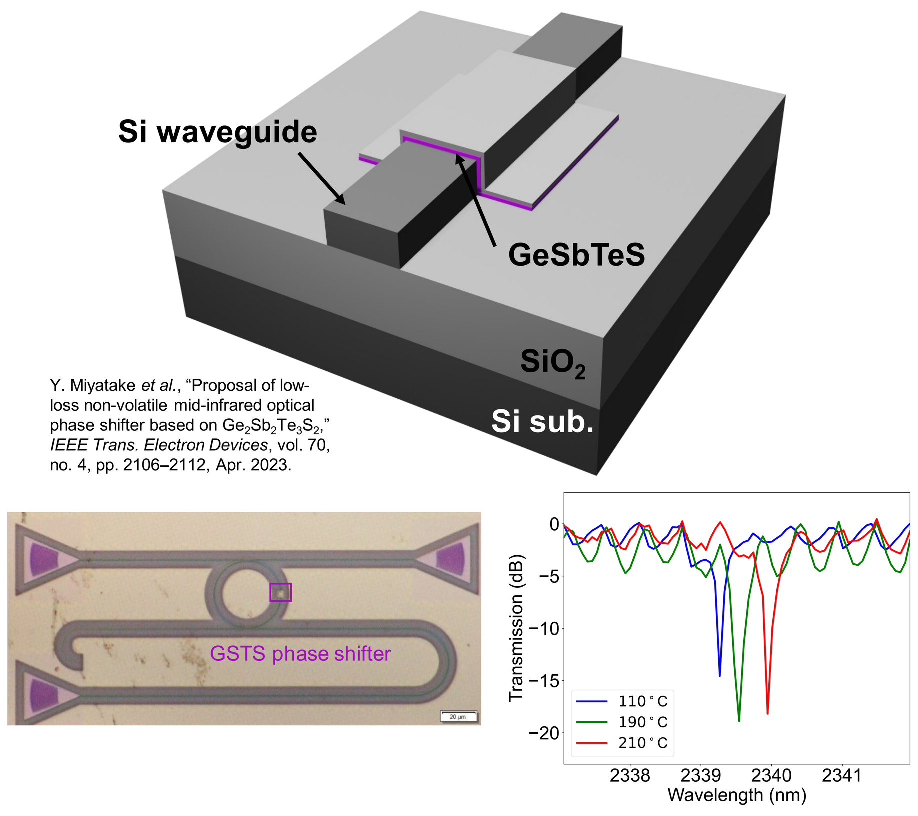
III-V/Si hybrid MOS optical phase shifter





- n-type InGaAsP membrane is bonded on Si waveguide with Al_2O_3 gate dielectric.
- Electron accumulation at the III-V MOS interface enables efficient, low-loss optical phase shift.
- The power consumption is 106 times smaller than that of TO phase shifter.

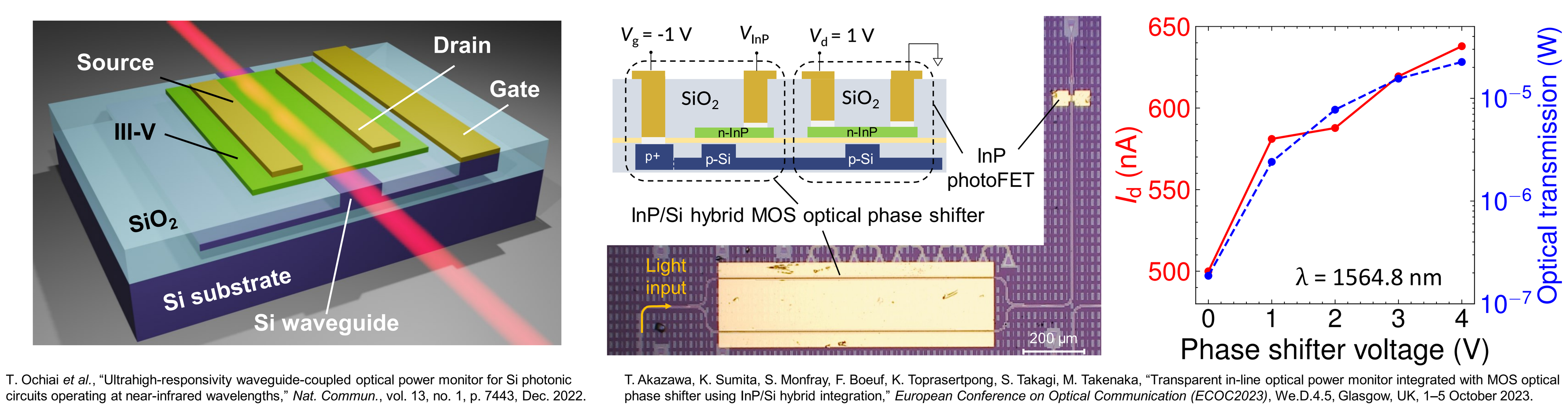
PCM optical phase shifter



- Low-loss optical phase shifter was demonstrated using a newly developed PCM, GeSbTeS.
- 0.29 dB for π phase shift, which is the lowest among the PCM phase shifters.

3. Optical power monitor

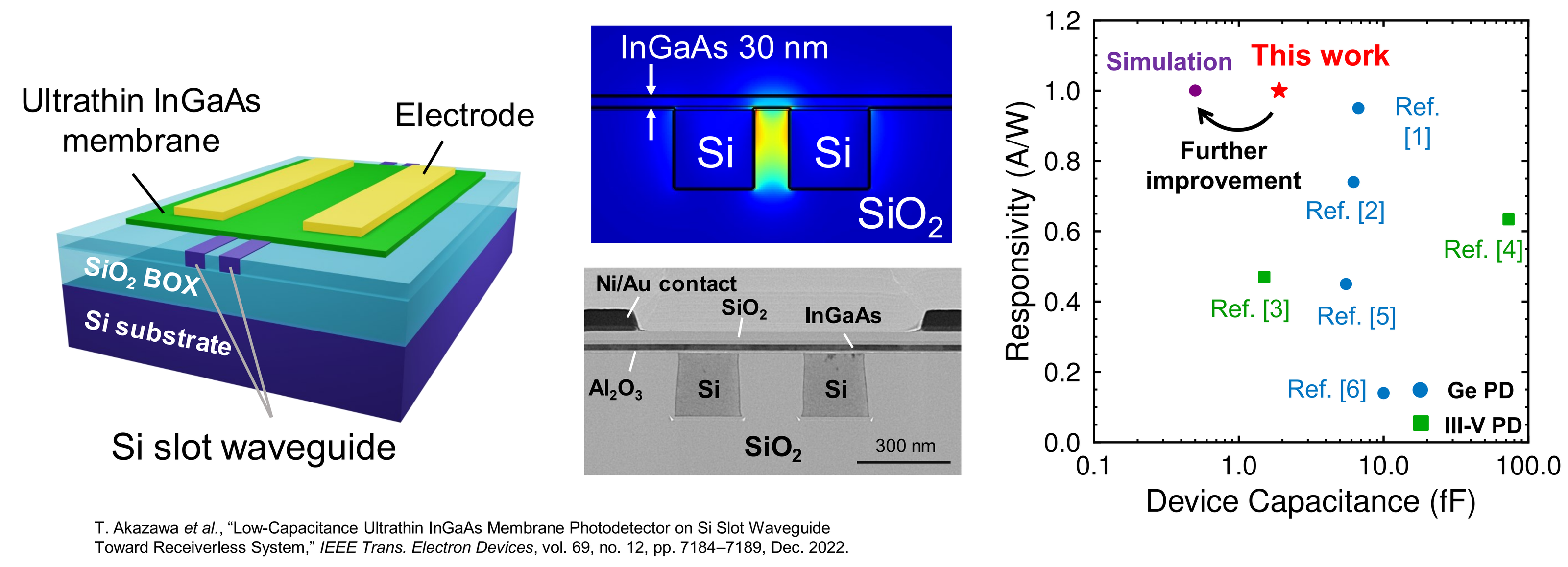
III-V/Si hybrid waveguide-coupled phototransistor



- InGaAs channel is bonded on Si waveguide with Al_2O_3 gate dielectric.
- Effective gating of InGaAs through Si waveguide gate electrode enables high responsivity of 10^6 A/W without gate metal loss.
- Monolithically integrated with MZI switch as an in-line optical power monitor.

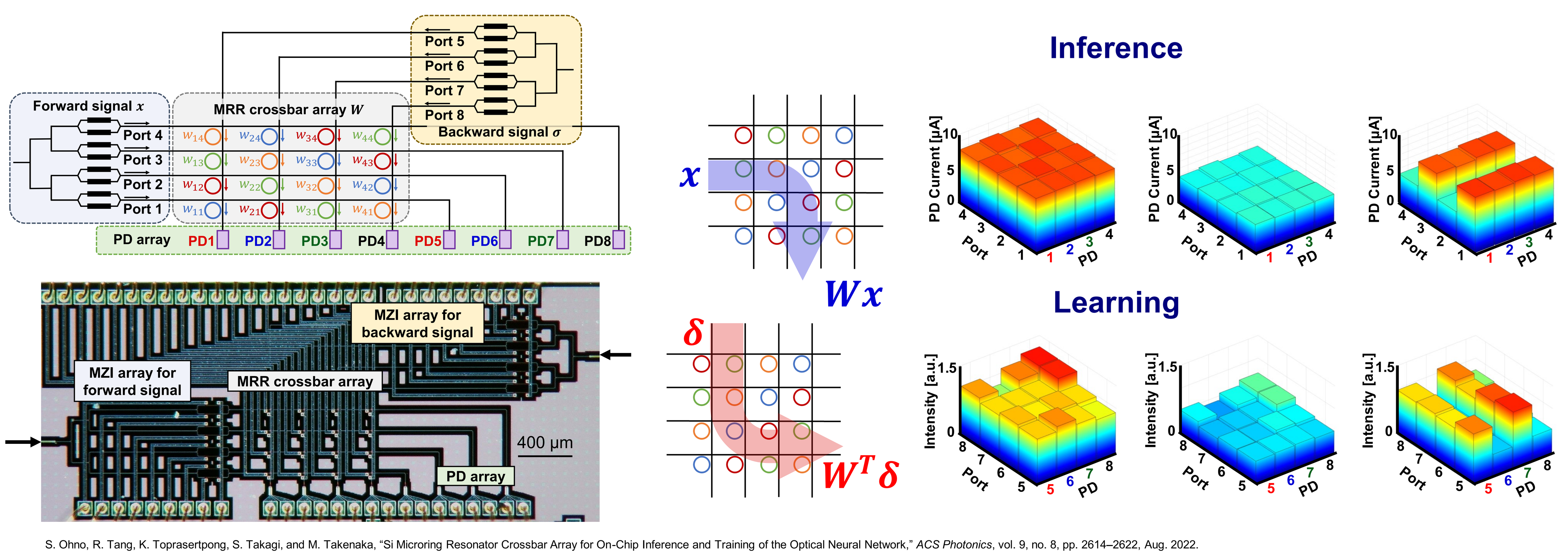
4. O/E converter

III-V/Si hybrid photodetector



- InGaAs membrane is bonded on Si slot waveguide.
- Due to the optical confinement in the gap of the slot waveguide, the absorption in InGaAs absorber is enhanced, resulting in high responsivity (1 A/W) and low parasitic capacitance (1.9 fF).
- Low-power O/E converter is expected by removing power-hungry electrical amplifier.

4. Deep learning processor



- Microring resonator crossbar is proposed as a deep learning accelerator.
- MAC operation for inference can be performed by injecting WDM optical signal from the left side of crossbar.
- MAC operation with transpose matrix can be performed by injecting error signal from the top side of crossbar, enabling learning through on-chip backpropagation in optical domain.

Summary

- Heterogeneous integration of III-Vs and PCMs enables high-performance and low-power deep learning processor.
- Using crossbar circuits, both learning and inference can be performed in the optical domain.
- Si programmable PIC can be used for various applications including deep learning, quantum computing, communication, and sensing.

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