From 'Optical Synapses' to a 'Photonic Brain' --- Integrated Photonic Neural Networks Toward Low-Power General-Purpose

SHANNON, CLARE, IRELAND, February 5, 2026 /EINPresswire.com/ -- A new publication from Opto-Electronic Technology; DOI 10.29026/oet.2025.250011, discusses integrated photonic synapses, neurons, memristors, and neural networks for photonic neuromorphic computing.

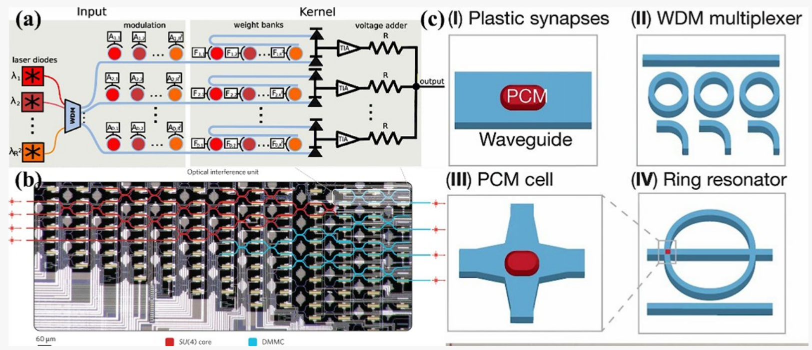

Fig. 1 Photonic integrated synapses

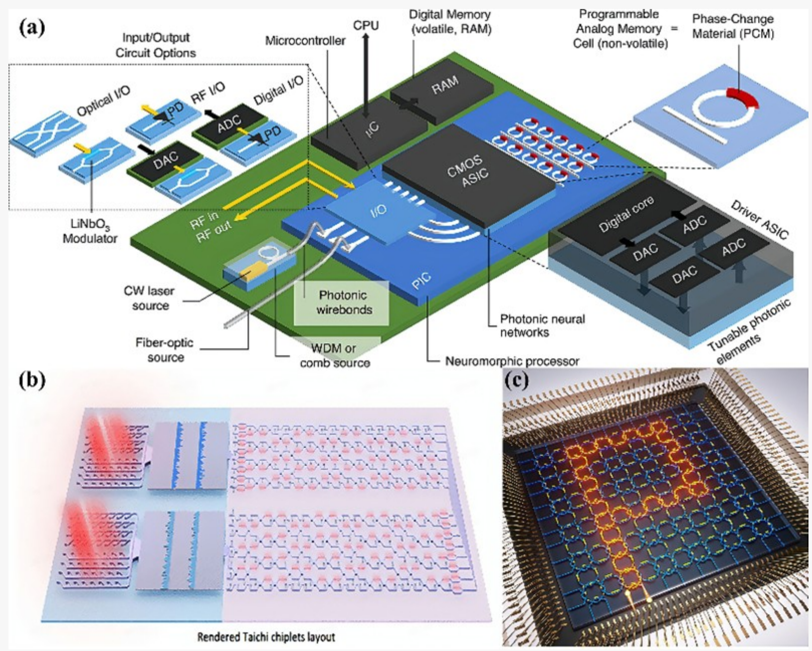

Fig. 2 The next generation of optical neural networks

As large-scale models and edge intelligence rapidly proliferate, computing systems are increasingly constrained by a triple bottleneck: insufficient bandwidth, excessive power consumption, and slow data movement between memory and computation. In the conventional von Neumann architecture, where memory and computing units are physically separated, data must be shuttled back and forth repeatedly across and within chips, causing latency and energy costs to grow sharply with system scale. Against this backdrop, neuromorphic photonics—which uses light as the information carrier—has attracted substantial attention. Light inherently offers ultra-high bandwidth, low latency, and massive parallelism, and can execute core operations such as matrix-vector multiplication during propagation. This opens a path to transforming AI inference from a major power consumer into a “light-speed, low-power” paradigm.

In this review, the authors focus on integrated photonic neural networks (IPNNs) as a key hardware route and systematically summarize three foundational device classes: photonic synapses for weight storage and loading, photonic neurons for nonlinear activation, and photonic memristors for short-term and long-term memory. The article further surveys multiple IPNN architectures and the latest advances, and discusses the critical issues that must be addressed for practical deployment—namely calibration and stability, photonic-electronic co-integration, programmable general-purpose architectures, and efficient training strategies—thereby providing a roadmap toward photonic AI chips that are low-energy, scalable, and trainable.

A research team led by Academician Gu Min at the University of Shanghai for Science and Technology (USST) was invited to publish a review article entitled “Integrated photonic synapses, neurons, memristors, and neural networks for photonic neuromorphic computing” in Opto-Electronic Technology (2025, Issue 3). The review centers on the critical chain from devices to systems for IPNNs, spanning device principles—network architectures—engineering translation. It examines in depth three key building blocks-photonic synapses, photonic neurons, and photonic memristors-and their roles in neuromorphic computing, systematically summarizes major technological progress in the field, and outlines future directions.

The article introduces photonic synapse devices like MRRs, MZIs, and PCMs (Fig. 1), which store neural-network weights. MRRs are compact and energy-efficient, while non-volatile PCMs excel in weight storage. These components enable low-power, highly parallel photonic computation.

It then explores photonic neurons for nonlinear activation, favoring all-optical schemes for efficiency. Photonic memristors, categorized as non-volatile (long-term storage) and volatile (fast temporal processing), provide optical memory. The review details four IPNN architectures: coherent networks (e.g., MZI meshes) enabling on-chip training; parallelized IPNNs using multiplexing for high throughput; integrated diffractive networks for low-latency inference; and reservoir computing for dynamic signal processing. Large-scale deployment hinges on both device performance and system-level capabilities like stability and trainability.

The review concludes that IPNNs hold great potential for low-power, high-performance computing. However, commercialization faces challenges in stability, integration density, and system-level engineering. Innovations in optoelectronic hybrid integration and programmable platforms (Fig. 2) are expected to overcome these hurdles, enabling future adoption in edge computing, autonomous driving, and intelligent manufacturing.

Overall, IPNNs are forming a clear trajectory in which devices are feasible, architectures are scalable, and systems are trainable. Nevertheless, achieving general-purpose, low-power photonic AI will require breakthroughs in low-energy nonlinearities and storage, calibration stability for large-scale arrays, photonic-electronic co-packaging, and programmable general-purpose architectures. As phase-change materials, microcombs, multidimensional multiplexing, and chiplet-based integration continue to advance, photonic neuromorphic computing is poised to be deployed first in edge-intelligence and real-time inference scenarios.

Keywords: neuromorphic photonics, integrated photonic neural networks (IPNNs), photonic integrated circuits (PICs)
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The School of Intelligent Science and Technology at USST, founded under the leadership of Academician Gu Min, is committed to becoming a world-class research institute in optical artificial intelligence and to cultivating interdisciplinary top talents with strong innovation capabilities and an international perspective. The team currently comprises more than 60 members; its faculty and researchers largely hold doctoral degrees from leading domestic institutions and top overseas universities. Research directions span frontier areas including intelligent photonic devices, all-optical learning, nano-lithography, optical data storage, neurobiological imaging, orbital angular momentum, and energy photonics. Through deep interdisciplinary research, the team has achieved a series of high-impact results. Related work has been published in top international journals such as Nature, Science, Nature Photonics, and Nanotechnology, demonstrating strong international academic influence. The school is supported by world-class experimental infrastructure and has been approved for multiple provincial and ministerial-level research platforms, including the Shanghai Frontier Science Research Base for Brain-Inspired Photonic Chips. The research center has established over 2,000 m^2 of laboratory space, encompassing optical laboratories, materials laboratories, bioimaging laboratories, and a state-of-the-art cleanroom micro-/nano-fabrication platform, providing robust support for cutting-edge research.

Weihong Shen is a specially appointed associate research fellow and a master’s supervisor. She received the Ph.D. degree in Electronic Science and Technology from Shanghai Jiao Tong University in September 2022. Her research focuses on integrated photonic chips and photonic neural networks. As first author or co-first author, she has published six SCI-indexed journal papers in venues including Photonics Research, and she leads a National Natural Science Foundation of China (NSFC) Young Scientists Fund project as well as the Shanghai “Magnolia Talent Program” Pujiang project.

Min Gu is the Director of the Photonic Chip Research Institute at USST, a Foreign Member of the Chinese Academy of Engineering, and a Fellow of the Australian Academy of Science as well as the Australian Academy of Technological Sciences and Engineering. He has published four English monographs, one Chinese translated work, and one edited English volume, and has authored more than 600 papers in internationally recognized leading journals in nano- and biophotonics (including Nature, Science, and Nature Photonics). He is a Fellow of IEEE, SPIE, Optica (formerly OSA), the Institute of Physics (IOP), the Australian Institute of Physics (AIP), and the Chinese Optical Society (COS). Academician Gu has received numerous honors, including the Beattie Steel Medal (Optical Society of Australia), the Ian Wark Medal (Australian Academy of Science), the Boas Medal (Australian Institute of Physics), and the Victorian Science and Innovation Award. He received the Dennis Gabor Award from the international optics and photonics community in 2019, the Emmett N. Leith Medal from Optica (formerly OSA) in 2022, and the Shanghai “Magnolia Silver Award” in 2023.

Qiming Zhang is a professor and doctoral supervisor and serves as the executive vice dean of the School of Intelligent Science and Technology at USST. He obtained a Ph.D. in Optics from the Department of Optical Science and Engineering, School of Information Science and Technology, Fudan University in 2011. His research interests include AI-enabled micro-/nano-photonic devices, optical information storage, and femtosecond laser processing. He currently leads major projects such as a key national R&D program and NSFC General Program projects, and has received multiple national-level young-talent awards and provincial/ministerial-level talent honors. He has published more than 60 research papers in journals including Science, Nature Communications, and Nature Reviews Materials.

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Opto-Electronic Technology Editorial Office
Opto-Electronic Technology
oet@ioe.ac.cn
