EDITORIAL | APRIL 01 2026

Guest Editorial: Optical computing systems FREE

Special Collection: Optical Computing Systems

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APL Photonics 11, 040401 (2026)
https://doi.org/10.1063/5.0333273

APL Photonics EDITORIAL pubs.aip.org/aip/app

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Cite as: APL Photon. 11, 040401 (2026); doi: 10.1063/5.0333273
Submitted: 10 March 2026 • Accepted: 16 March 2026 •
Published Online: 1 April 2026

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Note: This paper is part of the Special Topic on Optical Computing Systems.
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ABSTRACT

Optical computing benefits from low-loss signal transmission, wide optical bandwidth, and orthogonal multiplexing schemes to address energy and throughput challenges posed by state-of-the-art electronic processors. When an optical processor is synergistically combined with an electronic one, the hybrid system offers ultra-low latency and energy-efficient optical and high-resolution electronic signal processing. Scalable and practical realization of optical computing systems requires research across various aspects, including hardware and control, as well as design algorithms. The field of optical computing is witnessing accelerated progress, with many research groups in academia and industry contributing to it. This Special Topic Collection focuses on significant advances in the field of optical computing and presents the latest theoretical and experimental research results in this area.

I. LINEAR AND NONLINEAR OPTICAL COMPUTING

Recently, integrated and free-space optical computing architectures have been demonstrated, with linear and nonlinear computation, algorithms, and design strategies targeted. This collection presents several of these aspects, and on the linear computation side, Hung *et al.* introduce a compact photonic neuromorphic processor that integrates with an on-chip diffractive optical convolution unit to enable parallel, high-complexity vision perception and achieve an energy efficiency exceeding 100 (GOPS/W/mm^2).[1] In another work, Pappas *et al.* experimentally demonstrate a novel photonic AI accelerator using a multidimensional arrayed waveguide grating router and can execute tensor multiplications at a record-high total computational power of 262 TOPS.[2] On the nonlinear computation side, He *et al.* show an all-optical nonlinear activation function based on two-photon absorption in silicon and germanium waveguides.[3] In addition, Liu *et al.* introduce the use of periodic nanohole arrays in metasurfaces to provide a compact and precise optical neuron structure.[4]

II. APPLICATION-SPECIFIC SYSTEMS

In addition to specific mathematical operations, system-level implementations tailored to specific applications are critically important. Along this line, Wu *et al.* demonstrate a photonic sensing-processing architecture that embeds an optical Fourier transform architecture implemented by a frequency-shifting loop directly into an FMCW Li-DAR system for ultra-low-latency spectral-resolving for coherent ranging.[5] In a different application, Wu *et al.* experimentally demonstrate a hybrid compressive optical–digital neural network designed to facilitate both real-time THz imaging and precise extraction of object information.[6] Content-addressable memory circuits enable parallel, high-speed search operations for data-intensive applications, and Kaiser *et al.* report an optical content-addressable memory architecture using silicon photonic micro-ring resonators and photodiode-based latch structures to store data and execute ultra-fast pattern-matching entirely in the optical domain.[7]

III. DESIGN ALGORITHMS AND FRAMEWORKS

Design and training algorithms and frameworks are equally important. Integrated Mach–Zehnder interferometer (MZI) meshes have been a promising platform for implementing optical linear processors. Hamerly *et al.* introduce the concept of a phase-efficient circuit architecture and derive a universal information-theoretic limit to the phase-shift efficiency of universal multiport interferometers based on a modified MZI design.[8] In this line of research, Cavicchioli *et al.* propose a data-driven approach for controlling meshes of thermally tunable MZIs, which exploits a machine learning model trained to compensate for these non-idealities by pre-adjusting the electrical power given to integrated phase shifters.[9]

IV. DIFFRACTIVE OPTICAL PROCESSORS

Diffractive optical processors provide large-scale, high-throughput optical computing platforms. Li *et al.* propose an optimized dimension-reduction algorithm based on an improved Fisher score to directly filter the diffractive information injected into the optical network, enabling diffractive neural networks to obtain inputs with stronger resolving capabilities.[10] Ma *et al.* introduce a mutual learning knowledge distillation framework for optical diffractive neural networks, synergizing photonic computing with adaptive training strategies.[11] Finally, Clark *et al.* target metasurface topology optimization by comparing two pixel-based methods with neural-network-based parameterizations, in which the neural-network parameters are trained to output a metasurface design.[12]

V. CONCLUSION

In recent years, research efforts in optical computing have accelerated significantly, and we are witnessing great progress across various aspects of this technology. Optical computing has substantial potential to synergistically combine with electronic counterpart systems and make a whole that is greater than the sum of its parts.

AUTHOR DECLARATIONS

Author Contributions

A. Ozcan: Writing – original draft (equal). **X. Lin**: Writing – original draft (equal). **C. De Angelis**: Writing – original draft (equal). **F. Ashtiani**: Writing – original draft (equal).

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