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Special issue on digital and intelligent optics

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Innovations in artificial intelligence have revolutionized various areas, especially optics. The rapid development of novel optoelectronic devices at nanoscale has exhibited the multiple functionalities, high integration, compactness, fast modulation and scalability, showcasing new breakthroughs of digital optics and optoelectronic processors for intelligent computations. Tremendous applications have been actively explored, such as optical neural network, photonic integrated circuits (PICs), computational imaging, bio-sensing and many others. In this special issue, we have collected five papers reporting the high-impact researches in this domain, covering from the optical intelligent hardware, novel light sources to their practical intelligent design models and emerging applications.

There are several examples of optoelectronic PICs to use photons for information processing. Numerous architectures have been extensively studied including the Mach-Zehnder Interferometer (MZI) mesh arrays[1−5], micro-ring resonators (MRR)[6−8], neuromorphic computing with phase change materials[9−11], and others[12−15]. Along with these technological advancements, exploring new application scenarios of these PIC computations is also important as it helps to attract more efforts/investment into this field and to drive the novel task-specific PIC computing architectures.

Here, Dong et al. has demonstrated the integrated photonic convolution acceleration core (PCAC), with purpose-oriented functionalities for smart wearables with edge computing capabilities[16]. The team used the MRR arrays for convolution operation at the speed of light with 7-bit accuracy and extremely low power consumption, which can be a scalable solution of PICs. The computing capability is 3.2 TOPS (tera operations per second) in parallel processing. This has allowed image convolution and gesture recognition, important for new applications for wearable devices.

Dong's team used the external light source and fibre-based MUX for their exciting proof-of-concept demonstrations. From the practical viewpoints, the further advancement could be broadband light source and integrated multiplexer, which hopefully can be tailorable on a chip. The on-chip frequency comb will be a great candidate as light source. This can be obtained via nonlinear optical processing, the RF electro-optical modulation and others, and further feedback loop can be included for phase-locking mechanism.

In one cover of this special issue, Xie et al. has reported the flat broad frequency-comb with near-zero dispersion[17], which is one of the holy grail in this field. Their repetition frequency is around 190 GHz, covering 1470-1670 nm (70% of the entire spectral range). They have also efficiently packaged the optical chip in the way of edge coupling (coupling loss is less than 1 dB) and can be

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stable more than 8 hours with the feedback control system as demonstrated. Such flat combs will enable the next-generation compact source-embedded PICs[18–20] and even high-dimensional photonic computing solutions[4,21].

Last, these PICs composed of nanophotonic building blocks such as waveguides, multiplexer/demultiplexer and others usually rely on the optimized structural design. Conventional approach is the brutal-force simulation where one would sweep all possible configurations and choose the one which gives the results closest to the target. This method is not efficient and does not meet the ever-increasing demand of fast design of intelligent photonic systems. In this special issue, Yu et al. has proposed the anisotropic inverse design of on-chip photonic elements based on lithium niobate on insulators (LNOI)[22]. Importantly, this represents one of a few works for inverse design of complicated media, anisotropic media specifically here. The authors exploit the rank-3 dielectric matrix in FDTD simulations and apply the adjoint method to reduce the computational complexity. Therefore, the compact four-channel wavelength division demultiplexer with high figure of merit has been designed based on LNOI, offering a new opportunity to further miniaturize the PCAC demonstrated by Dong's team.

Also included in this special issue are two papers on how emerging intelligent optoelectronic system and computing algorithms can innovate the bio-imaging applications. Another cover paper, contributed by Luo et al. has reported a synthetic wave microscopy (SWM) with the metalens system for 3D super-resolution label-free microscopy[23]. Specifically, they vary the phase of various ways slowly to decouple the interferometric signals from the incoherent, non-modulating background, thus achieving 4× faster imaging speed (up to 10^6 pixels/s). Combining with metalens, the high lateral resolution of 0.42 λ/NA is also realized. Meanwhile, Zhao et al. here also reported a smart and compact Palm-size Optofluidic Hematology Analyzer based on a miniature fluorescence microscope and a microfluidic platform[24]. The dimension of gadget is 35 × 30 × 80 mm and the mass is of 39 g. Via leukocyte counting algorithms, automatic concentration detection has been realized with high fidelity of 95% limits, ranging from -0.93×10^3 to 0.94×10^3 cells/μL. The work promises the practical miniaturized[25] and intelligent optoelectronic system for the imaging and monitoring biosamples with high spatial and temporal resolution[26].

In summary, this special issue has broadly covered the optoelectronic sciences and technologies from the integrated photonic processors, the novel design, integrated light sources and practical applications from the wearable devices, portable microscope and high-end bio-imaging systems. Moving forward, we anticipate the optoelectronic sciences and technologies will offer the paradigm shift of digital and intelligent photonic applications. We also greatly thank all contributions from the authors, reviewers, and the scientific editor, Prof. Lianwei Chen, and very much hope the readers from broad communities enjoy this special issue as we did.

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Competing interests

The authors declare no competing financial interests.