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Editorial

Nanophotonics and Integrated Photonics

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Nanophotonics, a field combining photonics and nanotechnology, focuses on the mechanism and application of light–matter interactions at the nanoscale. Fueled by advancements in nanofabrication techniques and optical technology, nanophotonics has seen remarkable progress in recent years. Nanophotonics encompasses various subfields such as near-field optics, super-resolution microscopy, photonic crystals, diffractive optics, plasmonics, nano-optoelectronics, two-dimensional materials, and metamaterials. Nanophotonics led to the discovery of novel optical phenomena and has applications in the fields of highly sensitive detection, biochemical sensing, and communications [1,2].

Nanophotonics allows for the unprecedented control and manipulation of light at the nanoscale through the use of nanostructured materials and devices, which can break through the diffraction limit of light and regulate the performance of light emission and absorption more finely. Conceptually, research on nanophotonics can be divided into three fields: the nanoscale limitation of light, the nanoscale limitation of matter, and nanoscale light processing. One way to trigger light–matter interactions at the nanoscale is to limit light to a nanoscale much smaller than its wavelength, and the second way is to limit the size of matter to a nanoscale, thereby limiting light–matter interactions to the nanoscale, which defines the field of nanomaterials. The last method is the nanoscale limitation of light processing, which can be used for nanoscale processing of the structural and functional units of photons.

Researchers in nanophotonics are currently investigating a diverse array of subjects and potential uses, including nanomaterials, photonic crystals, plasmonics, metamaterials, nanophotonic devices, optical interconnects, sensors and imaging, and energy conversion. There are some important research directions in the field.

The integration of quantum mechanics with nanophotonics shall pave the way towards the advancement of sophisticated quantum technologies [3,4]. These technologies encompass quantum communication, quantum cryptography, and quantum computing, where the precise control of nanoscale photons holds utmost importance for the creation and manipulation of quantum states.

The optimization of the design and performance of nanophotonic devices shall encompass the involvement of machine learning and artificial intelligence. These technological advancements shall facilitate the acceleration of innovation and exploration in the field of nanophotonics [5].

Nanophotonics potentially assumes a pivotal role in the progression of faster and more energy-efficient photonic computing devices. Optical interconnects and on-chip photonics are anticipated to become indispensable in addressing the limitations posed by conventional electronic circuits [6].

A significant emphasis shall be placed on the development of flexible and tunable nanophotonic devices [7]. These devices possess the ability to adapt to diverse conditions and applications, thereby endowing them with exceptional versatility across various industries ranging from telecommunications to healthcare.

Although significant progress has been made in the field of nanophotonics, there are still certain obstacles that need to be overcome. The enhancement of fabrication techniques is indispensable in order to enhance the accessibility and cost-effectiveness of these advanced technologies. Moreover, the establishment of interdisciplinary collaboration between physicists, engineers, and material scientists is crucial in order to propel innovation to greater heights.

Integrated photonics (IP) is a subfield of photonics in which multiple large-structured, large-size, discrete photonic waveguides and devices are fabricated on flat substrates made from materials such as silicon, silicon nitride or silicon carbide [8]. This technological breakthrough means that photonic integrated circuits can now process and transmit optical signals in the same way that electronic integrated circuits process and conduct electrical signals. These circuits have the characteristics of large bandwidth, low latency, low power consumption, and low interference.

Photonic integrated chips work by using photons to sense, process, and transmit information [9]. Using waveguides to control light, photonic integrated chips are comparable to the wires used to transmit electrical signals through total internal reflection. With waveguide connections, multiple components can be integrated and fabricated on a single substrate, creating robust and miniaturized solutions. Components in photonic integrated circuits can be passive and active. Examples of passive components are switches and multiplexers and filters. Active components include detectors and lasers as well as modulators and detectors.

Typically, on-chip integrated photonic waveguide devices include Mach–Zehnder interferometers, microrings/disks, waveguide gratings, couplers and other structures that provide a platform for on-chip photonic manipulation [10]. In the field of communications, array waveguide gratings (AWGs) are typical examples of photonic integrated chips, which are often used for the optical multiplexing and demultiplexing of wavelength division multiplexing (DWDM) fiber optic communication systems. The state-of-the-art on-chip electro-optical modulators are also based on Mach–Zehnder interferometers [11].

In automotive and materials manufacturing, IP can be used to monitor a vehicle's surroundings through sensor systems such as lidar (light detection and ranging). The technology also facilitates communication between vehicles and city infrastructure to improve driver safety. In the field of quantum computing, the proposal and development of optical computers is attributed to their potential advantages. Photons are different from electrons, as photons belong to bosons, do not carry electricity, and beams can pass in parallel or cross each other without affecting each other, with innate giant parallel processing ability [12].

With the gradual development of photonic integration and the increasing demand for photonic integration, the photonic integration of single materials can no longer meet the actual application requirements. At the same time, hybrid photonic integration occupies a place in photonic integration because of its simple and flexible implementation and independent fabrication between devices. It also greatly broadens the development space of photonic integration, meaning that photonic integration systems gain new impetus in technological progress. In silicon-based emission modules, because silicon with an indirect bandgap struggles to emit light, it is often mixed with III-V group or other materials in light-emitting modules. In the future, the advancement of heterogeneous hybrid integration technology will promote the rapid development of photonic chips integrated with multiple functional material platforms. For example, in recent years, a series of new photonic integrated materials have emerged, such as III-V group materials, silicon nitride, lithium niobate, silicon carbide, aluminum nitride and chalcogenide materials [13–15]. Therefore, photonic integrated devices based on new platform materials have greatly promoted the rapid development of optical information generation, modulation, exchange and processing.

Another development direction of IP is on-chip optoelectronic hybrid integration, which not only integrates photonic devices into one module, but also includes electronic devices. Compared with photonic integration, optoelectronic integration is more demanding, but at the same time, it can take advantage of photonics and electronics, and can combine electronic devices with integrated photonic devices through heterogeneous integration, providing a more energy-efficient way to improve the speed and capacity of data networks, reduce costs, and meet the increasingly diverse needs of various industries.

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