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Twenty Years of Photonics

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Looking back over the past two decades, a number of gratifying achievements in the photonics field can be listed in discovering new mechanisms, inventing new structures/materials, and exploring new applications.

All the optoelectronic devices operate based on the interaction between light and matter, which is essentially the interaction between various fundamental particles and quasiparticles. Over the past 20 years, significant advances have been made in the understanding of the new mechanisms by which these particles interact with each other. Benefits from the progress of micronano processing technology, new structures, or materials help us to validate these new mechanisms and use them to develop devices.

First, beyond the classical interaction between electrons and photons, a series of quasiparticles have stepped onto the stage and, together with nanostructures or metamaterials, contributed to realizing new functions of photonic devices. For example, phonons, typical quasiparticles, can interact with photons through an optomechanical crystal, which is a kind of nanostructure combining with a photonic crystal and a phononic crystal and deals with the interaction between photons (light) and phonons (mechanical motion). It opens the door to the quantum ground state of macro-/mesoscopic objects, "ultimately-precise" measurement for a broad range of physical properties, such as mass, force, torque, magnetic field, and acceleration, and other fundamental investigations and applications. Excitons are another representative quasiparticle, whose transitions have been identified to present the basis of all recombination processes in quantum dots due to the overlap of the strongly localized electron and hole wave-functons, and make quantum dots show plenty of advantages even at room temperature. The two-dimensional materials, such as transition metal dichalcogenides or black phosphorus, also can keep the exciton state at room temperature and provide a new platform for studying excitonic devices. On the other hand, surface plasmon polariton (SPP), which is a special electromagnetic form formed by coupling an electromagnetic wave with metal-free electron density oscillation, is also considered as a kind of quasiparticle. The transport, coupling, and resonance properties of various SPP modes in metal nanostructures, as well as the interaction properties between SPP-enhanced light and matter, have been extensively studied. Different types of SPP waveguides, couplers, resonant cavity structures, high-sensitivity SPP biochemical sensor chips, SPP-enhanced light absorption solar cells, nanoscale SPP lasers, and nanoscale photolithography are reported using SPP to break the optical diffraction limit.

Except for these quasiparticles, free electrons have also become the new role of photonic devices breaking through the traditional device principle based on the interaction between bound electrons and light field in crystal. Through nanostructures or metamaterial, a new mechanism of interaction among the flying electrons on a chip, bound electrons in the crystal, and light field can be realized and opens a new way for the future photonic devices.

The research achievements of the past 20 years on new mechanisms, structures, and materials are important foundations for the development of photonic devices in the next 20 years. It is reasonable to expect "quasiparticle devices", such as phonon, exciton, and SPP devices, or on chip-free electron devices, to realize new functions that traditional photonic devices cannot achieve and to take a place in future photonic devices.

In terms of application, although it is hard to enumerate anything as socially influential as optical communication technology at the end of the last century, the penetration of many photonic technologies into the application field is commendable. Since entering the new century, the application of photonic technology has been extended from a mature optical communication to other fields, such as sensing, energy, medical, aerospace, and so on, and brought out a batch of notable technologies. One of them is the on-chip spectral measurement technology and even one-shot optical spectral imaging technology that enables real-time dynamic spectral imaging. This is not only very significant for almost all areas, such as hyperspectral remote-sensing imaging, noninvasive portable medical testing, and environmental monitoring, but will also provide a new paradigm for future intellisense.

When it comes to optical intelligence, a related topic is optical computing. A lightwave can carry and process information due to light propagation, parallel processing, and coherent control. With the development of deep learning and an artificial neural network (ANN), the optical neural network (ONN) has become a new research hotspot. Due to the limitation of optical−electric and electric−optical conversion, all-optical ONN is a very important development trend for the future. While another trend that should be noticed is to realize ONN on a photonic chip. With photonic integrated devices, it is helpful to release the requirement of optical alignment as well as the environmental vibration and temperature variation.

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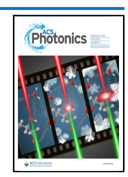

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Moreover, more devices can be integrated on a single chip to perform more complex functions.

Another application worth mentioning is optical quantum information. A photon is an ideal carrier of quantum information because of its fast propagation speed, difficult coupling with the outside world, easy to maintain quantum coherence, and it is easy to manipulate its quantum state. Actually, quantum computing has achieved considerable progress with a photonic platform at the same period of ONN and some hard computational problems, which are difficult to deal with by classical computers based on the von Neumann structure, can be efficiently solved. Of course, more research is being reported on quantum communication, such as quantum key distribution, quantum teleportation, quantum networks, and other quantum communication advances. Considerable progress has been made in the miniaturization and integration of key devices needed for the optical quantum system, including but not limited to a quantum light source, single photon detection, on-chip optical quantum state controlling, and so on. The integrated optical quantum chip technology, with significant advantages such as high stability, strong controllability, and easy expansibility, is regarded as an important platform to realize the functions of quantum communication, quantum computing, quantum simulation, and quantum precision measurement.

The next 20 years will usher in an era of vigorous development of photonic technology, both in cutting-edge research and technology applications. The accumulation of research in the field of photonics will bear fruit in the next 20 years. Breakthroughs at the device level will revolutionize the system. New devices will emerge in the new wavelength band, such as in the ultraviolet or terahertz range. Lidar may be ready for widespread use, and virtual/augmented reality technology will bring people different experiences. The research of optical computing will attract more attention. Optical quantum technology will be active in the field of precision measurement and sensing, including the quantum-effect-based electromagnetic field, gravity field detection technology, single photon imaging, and so on.

Let us look forward to the future.

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Notes

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