COMMENTARY

PHOTONICS INSIGHTS

Metalenses for revolutionary imaging

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Imaging tasks are becoming increasingly complex due to continuous high-tech advancements and the proliferation of personal electronics. From the high-resolution displays on our smartphones and laptops to advanced medical imaging systems, imaging systems are constantly being pushed to their limits. As complexity increases, more advanced optics are required. The development of new optical devices is an ongoing process as researchers and engineers strive to create better and more efficient ways to manipulate light. From tiny microlenses that can focus light onto a single point to advanced imaging systems that can capture ultrahigh-resolution images, the field of optics is constantly evolving. Metalenses show unique advantages in this trend because their artificial surfaces comprise customized meta-atoms, providing the potential for compact and efficient light manipulation. In today's optical demands, advanced optical lenses are expected to have high resolution, broadband operation, wide fields of view, high brightness, multi-functionality, etc. In recent years, metalenses that address these needs have been rapidly developed. Chen *et al.* proposed a high-numerical-aperture aplanatic metalens and utilized large diffractive chromatic dispersion for the spectral imaging system[1]. Chromatic dispersion can be manipulated to access spectral focus tuning and optical zooming in the visible spectrum without any mechanical movement. The aplanatic metalens with a high numerical aperture ensures high longitudinal and lateral resolutions. Xu *et al.* proposed a polarization multiplexed metalens array for ultra-compact wide-field microscopy[2]. The two sets of focusing phase profiles intersect with each other for two orthogonal circular polarizations. This imaging metalens with orthogonal circular polarization can obtain two sets of sub-images. Through imaging post-processing and mutual compensation of blind spots, a complete wide-field microscope image can be obtained. Ye *et al.* further demonstrated a chip-scale metalens array microscope for wide-field and depth-of-field imaging[3]. The polarization multiplexing and filtering functions have been integrated to effectively filter out background noise and greatly improve imaging quality.

Li *et al.* currently provide a review article on the developing roadmap of the flat lens[4]. They discuss novel imaging applications via flat optical lenses, such as superlenses, hyperlenses, metalenses, and multilevel diffractive lenses. With the rapid development of the field of flat optical lenses, this is an excellent point in time to summarize the fundamental principles, design, implementation, and novel applications of flat optical lenses. Li *et al.* offer a systematized literature review on metamaterials, metasurfaces, and metalenses for meta-imaging. New physics behind meta-optics are revealed, and novel metalens applications are explored. Due to the advances in micro/nanofabrication technologies and the increase in computer power, subwavelength artificial structures have enabled the emergence of new concept metasurfaces and arbitrarily designed wave-functional materials for electromagnetic waves. Li *et al.* highlight the major progress of novel metalenses by refining the latest information from academia and industry. In addition to various novel functions such as polarization imaging and differential imaging, the performances of high efficiency, broadband achromatism, and having no aberrations are close to commercial imaging applications. Metalenses have two advantages of thinness and multi-functionality, which are very conducive to the development of current optical devices towards ultra-miniaturization and high integration. Revolutionary metalenses will have significant advantages and unshakable roles in future imaging devices and systems.

Based on these critical meta-imaging applications, we discuss one of the most intriguing, from our point of view: the miniaturization of imaging systems. Metasurfaces can greatly reduce the thickness of imaging components. However, to reduce the size of the entire imaging system, the design of the optical imaging path also needs attention. The pancake metalens camera has been demonstrated to reduce propagation space[5]. First, the pancake metalens camera replaces traditional refracting lenses with ultrathin metalenses. Second, the combination of metalenses and mirrors, also called meta-cavities, cleverly utilizes the space folding properties of polarization to further realize compression of the imaging system. Polarization folding effectively compresses the working distance of the imaging system and overcomes the problem of energy beam splitting in the traditional pancake system. It provides a new solution and design dimension for developing highly integrated imaging systems. A new type of meta-cavity combined with metalenses and the optical design method of polarization conversion can bring new physical effects and broader application scenarios.

The evolution of optical imaging systems depends on the continuous development of new technologies in meta-imaging. An increasing number of academic teams and industries are participating in the development of meta-optics. Sooner or later,

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metamaterial-based products and revolutionary applications will find their way into our everyday lives.

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