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# Editorial: Advanced flat optics for complex light manipulation

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Editorial on the Research Topic
Advanced flat optics for complex light manipulation

Unlike electronics, optics has not followed a kind of Moore's law. While technology has witnessed a continuous downscaling of electronic components and a progressive increase in computing power density, optics has remained reliant on traditional bulk elements for a long time. Nevertheless, standard optical components like lenses, prisms, mirrors, and their combinations have been the core elements in most light-based applications, spanning fields from life sciences to information and communication technologies. These components have driven research and development across many areas, including astronomy, medicine, biology, imaging, computing, and telecommunications. Only in the last decades the outbreak of nanofabrication techniques inflamed miniaturization and integration also in the optical domain, unlocking new possibilities and revealing unexpected phenomena. Diffractive optics [1], for instance, not only offered lightweight and compact solutions but also paved the way for increasing the density of functionalities. Metasurfaces, the latest evolution in optics [2], unveiled new degrees of freedom in light manipulation [3], enabling spin-dependent [4] and arbitrary vectorial wavefront shaping [5], and including aberration-free optical operations [6]. Alongside these new design and fabrication paradigms, optics has also experienced a widespread interest in controlling the spatial structure of light beams and generating complex spatially variant states, such as vector beams and other exotic configurations. Structured light [7] has inspired groundbreaking advancements in optics and photonics and has benefited from the concurrent evolution of flat optics, enhancing the integration of optical platforms and enabling previously unimaginable ways to manipulate light. The Research Topic aims to showcase the state-of-the-art in flat optics engineering and applications for light structuring and advanced applications, highlighting their pivotal role in shaping the future of optics and photonics.

Among all modern light-based technologies, augmented reality (AR) has gained widespread adoption in various applications, including gaming, education, healthcare, and manufacturing. Flat optical elements represent an enabling technology in near-eye displays (NED) [8], where integrated solutions are essential for lightweight and portable designs that enhance user comfort without affecting optical performance. To this aim, Hwang and Lee presented a holographic printing–recording technology for near-eye display through volume holographic grating analysis in hologram recording and reconstruction, proving its effectiveness in uniformly displaying AR contents of a large screen with reconstructed depth images, inspiring new practical advances in the field.

The review of Xu and Zhang details the principles and improvement schemes of optical edge detection technology, discussing also the research progress and application of scalar and vector vortex filters in nonlinear optics. While a scalar vortex filter achieves edge enhancement through the modulation of amplitude and phase [9], by introducing the polarization degree of freedom, a vector filter enables directional edge enhancement [10] by combining the effects of a vectorial point spread function and a polarizer in cascade. Extending the technique to the nonlinear field enables wavelength conversion, overcoming the limitations of infrared detectors and opening simultaneously to applications for infrared spatial filtering at the few-photon level, or other non-linear processes such as four-wave mixing. The design and exploitation of compact spatial filters are essential for their integration into modern microscopes and imaging tools.

Within the framework of metaoptics, the research of Vogliardi et al. leverages the unique capability of metasurfaces to control light, enabling the encoding of multiple operations into a single optical element. As a matter of fact, by manipulating both the dynamic and geometric phases of a light beam it is possible to design a metasurface acting differently on right-handed and left-handed circularly polarized beams [11]. This approach is exploited to shift the orbital angular momentum content of an input vortex beam by a spin-dependent amount, disclosing a compact and integrated solution based on dual-functional silicon metalenses for optical switching, routing, and computation.

Dynamic tunability is attractive but difficult to achieve in practice. Moreover, standard methods are hardly miniaturizable. Liquid-crystal spatial light modulations (SLM) [12] are complex and power-consuming control systems, characterized by slow deflection speeds, limited deflection angles, and temperature sensitivity. MEMS/NEMS provide a faster and more robust alternative, steering light beams through the rotation of micromirrors [13]. However, their applicability is confined to specific deflection angles due to their limited working states. On the other hand, the advent of metasurfaces promises innovative solutions also on this side. Hu et al. propose a dynamic beam forming and switching method inspired by the mode-hopping effect [14, 15] of lasers. As a proof of concept, they introduce the dynamic beam switching metasurface design, featuring cascaded metaoptics in the telecom infrared with an in-plane mechanical actuation system to finely tune the angular mode overlap and, therefore, the number, directions, and energy of the diffraction orders. The outlined architecture exhibits remarkably versatile functionalities with high speed and reduced degrees of freedom, promising potential applications in light detection and ranging (LiDAR), optical wireless communication devices, and optical switches.

In summary, this Research Topic discloses representative works on integrated optics state-of-the-art and applications for light shaping and control. We expect that this Research Topic will build a bridge among different research areas, further promoting the development of complex light manipulation based on advanced flat optics.

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