All-Optical Differentiator of Various Orders Based on Single-Layer Multiplexed Metasurfaces

Niu Liu [1], Zhelin Lin [1], Zhenyu Xing [1], Xinliang Zhang [1, *], and Cheng Zhang [1, *]

[1] *School of Optical and Electronic Information & Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, 1037 Luoyu Road, Wuhan 430074, China*

**E-mail: cheng.zhang@hust.edu.cn, xlzhang@mail.hust.edu.cn*

All-optical computing attracts significant interest over recent years by its advantages in low power consumption, fast processing speed, and parallel computing capability[1]. Differential operations play an important role in all-optical computing and are widely used in image processing, signal analyzing, and equation solving. Current methods, such as spatial Fourier transfer approach and Green's function approach, suffer from limitations including high system complexity and limited processing capability[2]. Here, we propose and implement a multifunctional single-layer metasurface, whose point spread function can be engineered independently for two orthogonal polarizations via the complex amplitude modulation technique, for directly imaging a target object and simultaneously performing differential operations with arbitrary orders. By employing a super-cell comparing four individual meta-atoms, independent manipulation of phase and amplitude over two orthogonally polarized incident beams can be realized by a single-layer dielectric metasurface, leading to polarization-switchable point spread functions and different order differentiation operations in the output images. As a proof of concept, a single-layer metasurfaces differentiator performing 1st/2nd-order multiplexed differentiations is designed, fabricated, and characterized. Experimental results of the PSF intensity profiles (Fig. 1b) and imaging performance (Fig. 1c) align well with theoretical predictions, demonstrating fine spatial resolutions up to 90.5 lp/mm. This work provides a novel route towards realizing ultra-compact all-optical computing devices and systems, which could facilitate an array of applications in biological imaging, information processing, and optical communication.

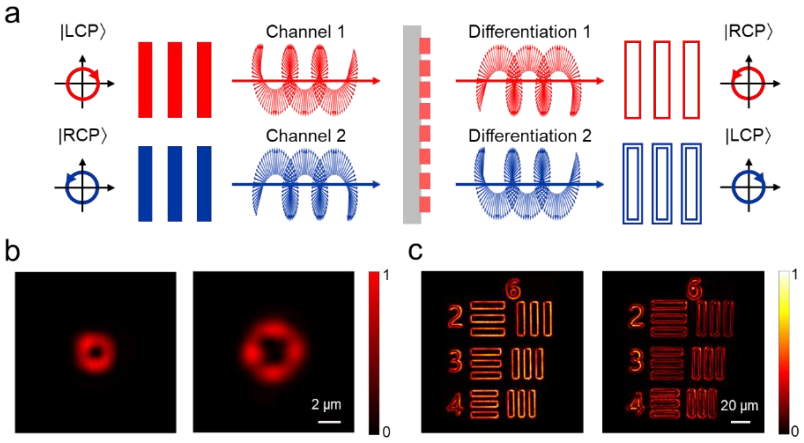

Fig. 1 (a) Schematic representation of the spin-multiplexed metasurface differentiator. (b) Measured PSF intensity profiles corresponding to 1st- (upper panel) and 2nd- (lower panel) order differentiation. (c) The 1st-order (upper panel) and the 2nd-order (lower panel) differentiation imaging results of the 1951 USAF resolution test chart.

References

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2. He S, Wang R, Luo H., Computing metasurfaces for all-optical image processing: a brief review, *Nanophotonics*, 11(6), 1083 (2022).