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A novel method for designing crosstalk-free achromatic full Stokes imaging polarimeter

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Metasurface-based polarimetry techniques have attracted lots of interests and been extensively studied in the past years, but are still hampered by narrow operating bandwidth and large crosstalk. Recently, Xian-Gang Luo's group proposed a new method of polarization-dependent phase optimization for the design of crosstalk-free, broadband achromatic, and full Stokes imaging polarimeter, which offers a promising platform for a wide range of applications including bio-photonics and integrated optics.

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Polarization comprises abundant information of substance, playing an essential role in light-matter interactions. Polarimetry, a method of determining the polarization states of the scene, has been widely adopted in remote sensing¹, biomedicine², astronomy³, etc. Conventional methods for polarimetry demand beam splitters, waveplates, and polarizers for measuring Stoke parameters in one shot, which ineluctably limiting their applications in compact and integrated optical systems.

Metasurface has made numerous impressive applications in imaging^{4,5}, holography^{6,7}, catenary optics^{8,9}, extraordinary Young's interference (EYI)¹⁰, and other areas for its flexible optical field modulation and potentials in highly compact integration due to ultra-thin nature¹¹⁻¹⁴. It also provides new routes for polarimetry. To date, various metasurface-based dielectric polarimeters have been developed, such as spectropolarimeters¹⁵, snapshot imaging polarimetry¹⁶, Hartmann-Shack wavefront sensor¹⁷, and wide-angle polarimetry¹⁸. Although the performance of polarimeters has made considerable headway, these polarimeters operate at a single

wavelength and have not taken into account the effects of polarization crosstalk.

Albeit some works attempted to extend the bandwidth of the polarimeter by using metagrating^{15,19}, these polarimeters implement broadband dispersion rather than achieving achromatic broadband, constraining the practical applications to a certain extent. Besides, tackling crosstalk between polarizations is often lacking, leading to significant errors in measurements. The approach of employing calibration matrix to correct the measurement error proves inadequate for accurately measuring unknown wavelengths in broadband^{17,20}. Thus far, characteristics of broadband achromatic and crosstalk-free is still an unreachable feature for metasurface-based polarimetry techniques.

In a recent paper published on *Opto-Electronic Advances*¹⁸, Xiangang Luo and his colleagues propose a method for the crosstalk-free achromatic full Stokes imaging polarimeter. The proposed broadband achromatic polarimeter is designed to effectively separate arbitrary incident light within the operational bandwidth into

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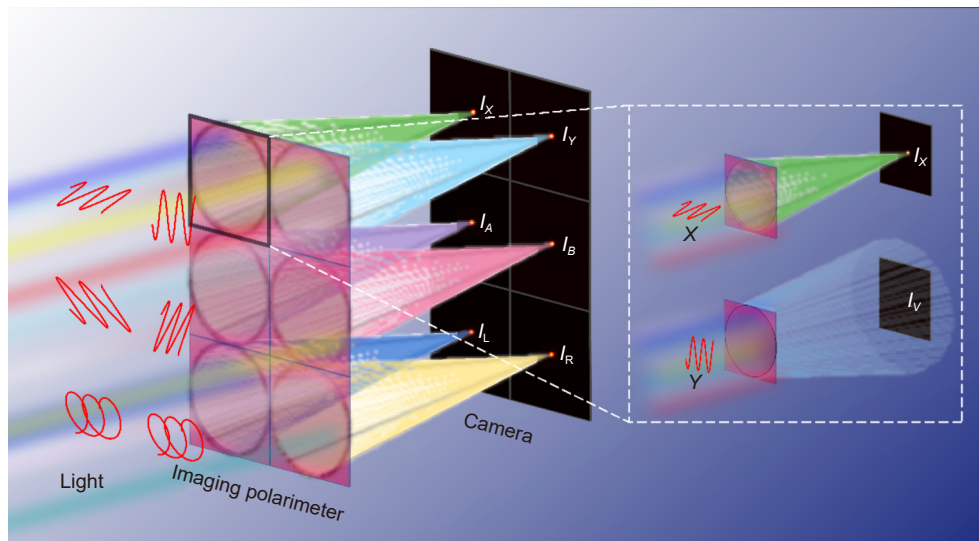


Fig. 1 | The schematic of crosstalk-free achromatic full Stokes imaging polarimetry metasurface enabled by polarization-dependent phase optimization. Figure reproduced with permission from ref.²¹, under a Creative Commons Attribution 4.0 International License.

different polarization channels, focusing them on a pre-defined focal plane, as illustrated in Fig. 1. The schematic within the white frame on the right depicts the underlying principle of polarization-dependent phase optimization, which mitigates crosstalk effects and enhances the accuracy of polarimetry measurements.

To execute the proposed methodology, a crosstalk-free broadband achromatic full Stokes imaging polarimetry based on dielectric metasurface is produced, which operates in wavelength range from 9 μm to 12 μm with a relative bandwidth of 0.2857. The polarimeter consists of 2×3 polarization-sensitive dielectric metalenses, elaborately designed by the particle swarm optimization (PSO) algorithm and polarization-dependent phase optimization method. The performances of the achromatic metalenses for linear (X , Y) and circular (L , R) polarizations are first verified. Both numerical simulations and experimental results demonstrate that these metalenses accomplish crosstalk-free polarization-sensitive achromatic focusing within the designated bandwidth. Moreover, the performance of the polarimeter is validated by illuminating various polarization states under 9.3 μm , 9.6 μm , 10.3 μm , and 10.6 μm wavelength. The polarimeter can directly and accurately measure without calibration at each wavelength, which is of great significance to the practicality of the device, because various influencing factors are considered in the early elaborate design. Finally, the polarization imaging performance is evidenced by utilizing a self-built polarization mask that carries polarization information.

This work envisions the powerful roles of the pro-

posed design methodology. The experimental results affirm that the designed polarization-sensitive metalenses effectively eliminate the chromatic aberration while exhibiting polarization selectivity and negligible crosstalk. Compared with the single-polarization optimization method, the average crosstalk has been reduced by more than three times for incident light with arbitrary polarization in a wavelength range from 9 μm to 12 μm , guaranteeing a more accurate measurement of the polarization state. This work could impact applications in wavefront detection, remote sensing, color imaging, and light-field imaging.

References

1. Tyo JS, Goldstein DL, Chenault DB, Shaw JA. Review of passive imaging polarimetry for remote sensing applications. *Appl Opt* **45**, 5453–5469 (2006).
2. Garcia M, Edmiston C, Marinov R, Vail A, Gruev V. Bio-inspired color-polarization imager for real-time in situ imaging. *Optica* **4**, 1263–1271 (2017).
3. González NB, Kneer F. Narrow-band full Stokes polarimetry of small structures on the Sun with speckle methods. *A & A* **480**, 265–275 (2008).
4. Fan YB, Yao J, Tsai DP. Advance of large-area achromatic flat lenses. *Light Sci Appl* **12**, 51 (2023).
5. Yang Y, Seong J, Choi M, Park J, Kim G et al. Integrated metasurfaces for re-envisioning a near-future disruptive optical platform. *Light Sci Appl* **12**, 152 (2023).
6. Gao H, Fan XH, Xiong W, Hong MH. Recent advances in optical dynamic meta-holography. *Opto-Electron Adv* **4**, 210030 (2021).
7. Anand V, Han ML, Maksimovic J, Ng SH, Katkus T et al. Single-shot mid-infrared incoherent holography using Lucy-Richardson-Rosen algorithm. *Opto-Electron Sci* **1**, 210006 (2022).
8. Pu MB, Li X, Ma XL, Wang YQ, Zhao ZY et al. Catenary optics

- for achromatic generation of perfect optical angular momentum. *Sci Adv* 1, e1500396 (2015).
9. Luo XG, Zhang F, Pu MB, Xu MF. Catenary optics: a perspective of applications and challenges. *J Phys Condens Matter* 34, 381501 (2022).
 10. Pu MB, Guo YH, Li X, Ma XL, Luo XG. Revisitation of extraordinary young's interference: from catenary optical fields to spin-orbit interaction in metasurfaces. *ACS Photonics* 5, 3198–3204 (2018).
 11. Luo XG, Zhang F, Pu MB, Guo YH, Li X et al. Recent advances of wide-angle metalenses: principle, design, and applications. *Nanophotonics* 11, 1–20 (2022).
 12. Guo YH, Zhang SC, Pu MB, He Q, Jin JJ et al. Spin-decoupled metasurface for simultaneous detection of spin and orbital angular momenta via momentum transformation. *Light Sci Appl* 10, 63 (2021).
 13. Yue Z, Li JT, Li J, Zheng CL, Liu JY et al. Terahertz metasurface zone plates with arbitrary polarizations to a fixed polarization conversion. *Opto-Electron Sci* 1, 210014 (2022).
 14. Fu R, Chen KX, Li ZL, Yu SH, Zheng GX. Metasurface-based nanoprinting: principle, design and advances. *Opto-Electron Sci* 1, 220011 (2022).
 15. Ding F, Pors A, Chen YT, Zenin VA, Bozhevolnyi SI. Beam-size-invariant spectropolarimeters using gap-plasmon metasurfaces. *ACS Photonics* 4, 943–949 (2017).
 16. Dai YM, Zhang YQ, Xie YP, Wang DP, Wang XY et al. Multifunctional geometric phase optical element for high-efficiency full Stokes imaging polarimetry. *Photonics Res* 7, 1066–1074 (2019).
 17. Yang ZY, Wang ZK, Wang YX, Feng X, Zhao M et al. Generalized Hartmann-Shack array of dielectric metalens sub-arrays for polarimetric beam profiling. *Nat Commun* 9, 4607 (2018).
 18. Zhang YX, Jin JJ, Pu MB, He Q, Guo YH et al. Full Stokes polarimetry for wide-angle incident light. *Phys Status Solidi (RRL) – Rapid Res Lett* 14, 2000044 (2020).
 19. Wu PC, Chen JW, Yin CW, Lai YC, Chung TL et al. Visible metasurfaces for on-chip polarimetry. *ACS Photonics* 5, 2568–2573 (2018).
 20. Wang YX, Wang ZK, Feng X, Zhao M, Zeng C et al. Dielectric metalens-based Hartmann–Shack array for a high-efficiency optical multiparameter detection system. *Photonics Res* 8, 482–489 (2020).
 21. Zhang YX, Pu MB, Jin JJ, Lu XJ, Guo YH et al. Crosstalk-free achromatic full Stokes imaging polarimetry metasurface enabled by polarization-dependent phase optimization. *Opto-Electron Adv* 5, 220058 (2022).