Metasurface Polarization Optics

Federico Capasso
Harvard University, Cambridge MA 02138 USA; e-mail: capasso @seas.harvard.edu

Metasurfaces, subwavelength spaced arrays of phase shifting elements, enable spatially varying control of polarization [1]. I will discuss J-plates, metasurface devices that impart two arbitrary orbital angular momentum (OAM) states on an arbitrary orthogonal polarization and their application in high OAM lasing and a new class of polarizers and waveplates that change their behavior along the beam's axis, thereby generating structured light with a polarization state the can traverse any trajectory on the Poincare' sphere [2]-[4] In metamaterials with freeform meta-atoms, one can engineer the optical anisotropy such that light sees different indices for arbitrary—linear, circular, or elliptical—orthogonal eigen-polarization states. Using topology-optimized metasurfaces, we demonstrated this arbitrary birefringence [5]. It has the unique feature that it can be continuously tuned from linear to elliptical birefringence, by changing the angle of incidence. In this way, a single metasurface can operate as many wave plates in parallel, implementing different polarization transformations.

We present a unifying formalism, Matrix Fourier optics, for understanding polarized light's interaction with obstacles that produce spatially-varying polarization transformation, such as metasurfaces [6]. This generalizes the ordinary description of optical fields in terms of a plane wave decomposition to include Jones matrix coefficients. We show how this formalism can be used to design metasurface gratings that analyze an arbitrary set of polarization states on their diffraction orders. We characterize these gratings and show that they exhibit high performance. These gratings enable full-Stokes polarization imaging with a single polarization component. We demonstrate practical polarization photography with a full-Stokes polarization camera built around one such metasurface grating, both indoors and outdoors in broad daylight. This camera promises wide-ranging applications in machine vision and remote sensing.

References

[1] J. P. Balthasar Muller, N. A. Rubin, R. C. Devlin, B. Groever, and F. Capasso "Metasurface Polarization Optics: Independent Phase Control of Arbitrary Orthogonal States of Polarization." *Physical Review Letters,* **118**, 113901 (2017)

[2] R. C. Devlin, A. Ambrosio, N. A. Rubin, J. P. Balthasar Mueller, and F. Capasso. "Arbitrary spin-to-orbital angular momentum conversion of light." *Science,* **358,** 6365, 896 (2017)

[3] H. Sroor, Yao-Wei Huang, B. Sephton, D. Naidoo, A. Valles, V. Ginis, C-W. Qiu, A. Ambrosio, F. Capasso, and A. Forbes "High-purity orbital angular momentum states from a visible metasurface laser." *Nature Photonics*, **14**, 498 (2020).

[4] A. H. Dorrah, N. A. Rubin, A. Zaidi, M. Tamagnone, and F. Capasso "Metasurface optics for on-demand polarization transformations along the optical path." *Nature Photonics* doi: 10.1038/*s41566-020-00750-2* (2021)

[5] Z. Shi, A. Y. Zhu, Zhaoyi Li, Yao-Wei Huang, Wei Ting Chen, Cheng-Wei Qiu, and F. Capasso "Continuous angle-tunable birefringence with freeform metasurfaces for arbitrary polarization conversion." *Science Advances,* **6**, 23 (2020).

[6] Noah A. Rubin, Gabriele D'Aversa, Paul Chevalier, Zhujun Shi, Wei Ting Chen, and F. Capasso "Matrix Fourier optics enables a compact full-Stokes polarization camera." S*cience* **365,** eaax1839 (2019)