URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

Time-modulated Metasurfaces for Generation of Dynamic Twisted Light Beams

Hooman Barati Sedeh(1), Mohammad Mahdi Salary(1), and Hossein Mosallaei*(1)
(1) Electrical and Computer Engineering Department, Northeastern University, Boston, MA 02115, USA
*e-mail: hosseinm@ece.neu.edu

Optical metasurfaces provide an unprecedented capability in engineering the wavefront of light through planar nanostructured platforms with ultra-compact footprints which have opened opportunities for designing complex flat optical components [1]. Among numerous other functionalities, metasurfaces can be used for introducing orbital angular momentum (OAM) to a light beam through imparting an azimuthal phase gradient to its wavefront. Such twisted structured light beams have been widely investigated due to high-dimensionality of Hilbert space of OAM modes and mutual orthogonality of distinct OAM states which can offer a wide range of applications [2] such as enhancing the channel capacity in communication systems, super-resolution and high-contrast imaging devices, optical tweezers, and multidimensional entanglement of photons. Despite the great progress made toward OAM generation via metasurfaces, one of the fundamental limitations of the proposed approaches is their static operation which does not allow for active tuning of generated OAM states. Recently, an immense effort has been put into introducing different tuning mechanisms into metasurfaces to overcome their fixed functionality and enable post-fabrication real-time tuning of the optical response via geometrically fixed platforms [3]. Nevertheless, these quasi-static metasurfaces typically suffer from a limited dynamic phase span and non-uniform amplitude during phase modulation which would result into low OAM mode-purity and significant cross-talk in a mode-multiplexed communication scenario. Furthermore, the generated structured light beams by static and quasi-static metasurfaces can only carry a time-invariant OAM at the steady-state.

In this work, we introduce topological space-time photonic transition of light within the emerging paradigm of time-modulated metasurfaces which yields a superposition of OAM-carrying light beams at distinct frequency harmonics upon scattering of light from an angular-momentum-biased metasurface whose topological charges and frequency shifts are correlated. The applicability of topological space-photonic transitions for active tuning of OAM states with high mode-purity is demonstrated which yields minimal crosstalk between OAM channels in a mode-multiplexed communication system. Moreover, the role of spatiotemporal modulation profile of the metasurface on the spectral and spatial diversity of OAM states is explored. It is shown that angular-momentum-biased metasurfaces allow opportunities for hybridized mode-division and wavelength-division multiple access through multiplexing and multicasting across distinct OAM states and wavelengths. The nonreciprocity of topological space-time photonic transitions across the temporal frequency domain and Hilbert space of OAM states is also investigated giving rise to distinct twisted light channels in up- and down-links. Furthermore, we demonstrate generation of structured light beams carrying a time-varying OAM in the steady-state through implementation of a time-modulated metasurface with an angular frequency gradient. The temporal dependence of OAM in the steady-state is a result coherent interference between scattered lights of different frequencies from different angular sections of the time-modulated metasurface. Such a time-varying dynamic structured light possesses a new property called self-torque, which can be used for unprecedented manipulation of nanoscopic and microscopic objects. The temporal dependency of OAM state also allows for time-division multiple access in optical communication. In order to realize time-modulated metasurfaces with angular-momentum-bias and angular frequency gradient, a reflective dielectric metasurface is considered consisting of silicon nanodisk heterostructures integrated with indium-tin-oxide and gate dielectrics placed on a back mirror forming a dual gated field effect modulator. The metasurface is divided into several azimuthal sections wherein the nanodisks are interconnected via biasing lines. Addressing each azimuthal section with radio-frequency biasing signals separately allows for angular-momentum-biasing and imprinting angular frequency gradient.

References

[1] N. Yu and F. Capasso, "Flat optics with designer metasurfaces", Nature Materials, vol. 13, no. 2, pp. 139-150, 2014.
[2] Y. Shen et al., "Optical vortices 30 years on: OAM manipulation from topological charge to multiple singularities", Light: Science & Applications, vol. 8, no. 1, 2019.
[3] L. Kang, R. Jenkins and D. Werner, "Recent Progress in Active Optical Metasurfaces", Advanced Optical Materials, vol. 7, no. 14, p. 1801813, 2019.