Polarization and directional degree of freedom in optical metasurfaces

Jonghwa Shin*, Joonkyo Jung, Hyeon Hee Kim, Nayoung Kim and Taeyong Chang
Department of Materials Science and Engineering, KAIST, Daejeon 34141, Republic of Korea
**E-mail:qubit@kaist.ac.kr*

Optical metasurfaces enable fine control over the scattering of light. In contrast to conventional optical elements, metasurfaces exhibit optical responses that are highly sensitive to the configuration of incident light, a feature that can be leveraged to construct novel devices with interesting functionalities. When modelling the metasurface as an abstract system with a “transfer function” dependent on parameters characterizing the incident light, the most obvious input parameters are the spatial point of incident on the surface and the light’s wavelength. Such dependencies are not exclusive to metasurfaces, as conventional optical components like microlens arrays, color filter arrays, and gradient index devices also exhibit them, albeit typically with lower spatial and spectral resolution.

A more significant departure from traditional optics lies in the strong dependence of metasurfaces’ optical responses on both the polarization and propagating direction of the incident light. Although birefringent materials like calcite and liquid crystals exhibit certain degrees of polarization sensitivity, metasurfaces are capable of producing much stronger effects. Notably, recent work has demonstrated that complete control over the passive, linear transmission of coherent light is achievable for any pair of orthogonal polarization states with a single metasurface [1].

Additionally, metasurfaces can be engineered to exhibit pronounced sensitivity to the direction of incidence. This directional sensitivity can be classified based on whether variations occur across different angles on the same side of the metasurface or between the "forward” and “reverse” directions of incidence, with metasurfaces lacking mirror symmetry offering unique possibilities in both cases. First, one can enhance angle sensitivity near normal incidence to achieve strong asymmetry with respect to the tilt of the wave vector of the incident light [2]. This principle can be applied to design overlapping metalens array that overcome the fundamental pitch-resolution trade-offs of conventional microlens arrays. Second, the inherent asymmetry in Jones matrices for "forward” and “reverse” directions can be exploited even within reciprocal systems [3]. Although reciprocity imposes certain constraints, it is still possible to design devices that appear to perform markedly different functions when flipped.

These examples illustrate the wide range of controllable properties related to polarization and incident angles, that metasurfaces afford. At the same time, a unified theoretical framework is essential for consistently describing the phenomena, promoting our exploration of possible formulations.

References

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