Wave Manipulation Using Metasurfaces

Nasim Mohammadi Estakhri and Andrea Alù
Department of Electrical and Computer Engineering, The University of Texas at Austin, Austin, TX 78712, USA

Metamaterials are a class of artificially engineered structures designed to provide anomalous properties that are unavailable or very weak in natural media, such as a negative index of refraction. Beyond their volumetric effects, two-dimensional metamaterials (or *metasurfaces*), may be designed to provide unique surface confined properties that are especially appealing for low-loss wavefront engineering and beam shaping. The physics of wave-matter interactions on the metasurface is similar to the one of an impedance surface, able to create abrupt and spatially inhomogeneous field discontinuities on an optical incident wave. So far, numerous studies have been focused on passive metasurfaces where the exclusive role of the surface is to impose a local phase discontinuity on the scattered wave in order to reconstruct the desired distribution of the outgoing wavefront [1]-[4]. A linear scattering phase profile, for instance, may create wave bending (Fig. 1a-b), while a hyperbolic phase distribution enables beam focusing effects (Fig. 1c-d). Recent studies pushed the limit of wavefront manipulation to more advanced functionalities such as surface carpet cloaking in which an ultrathin non-periodic surface wrapped around an obstacle intentionally mimics the scattering response of a flat surface and hides the underneath object (Fig. 1e-f). In our presentation, we discuss how this local phase compensation approach in passive metasurfaces neglects the effect of mutual scattering between surface components and suffers from significant impedance mismatch along the interface. While the efficiency of coupling to the desired wave is reasonably high for moderate wave transformations, extreme operations such as large-angle beam bending or focusing in the very near-field are unattainable using the local phase compensation approach. Our analysis provides the exact requirements on the surface profile to ensure 100% conversion efficiency to any desired outgoing wavefront and demonstrates the necessity of active surface elements in the optimal designs [5]. Based on the presented rigorous solution, we also develop a novel technique to design passive gradient metasurfaces with significantly improved efficiencies for various applications ranging from large-angle beam steering and near-field focusing to cloaking optically large objects, using a single ultrathin surface.

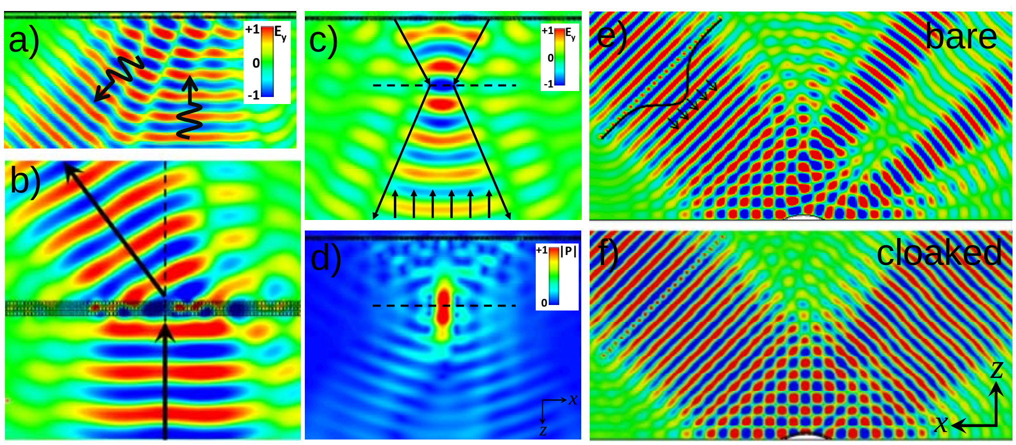

Figure 1. Optical wavefront manipulation with graded metasurfaces. (a)-(b) Wave deflection in reflection and transmission. Normally incident beam is efficiently redirected toward a predestinated direction based on proper arrangement of subwavelength nanoresonators over the surface [2],[3]. (c)-(d) Realization of ultrathin, integrable lenses [2]. (e)-(f) A graded metasurface is designed to compensate the unwanted scattering at the surface of an arbitrary obstacle and create an ultrathin, lightweight carpet cloak [4].

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