Graded Metareflectors for Wave Manipulation and Control at the Nanoscale

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Optical metasurfaces, or planarized metamaterials, are based on engineered subwavelength inclusions intentionally designed to provide desired advanced functionalities, unavailable with conventional gratings, by exploiting their anomalous localized response. Metasurfaces have been investigated both theoretically and experimentally in various recent studies, but most of the available examples are limited to strictly periodic structures. In this work we introduce a novel planarized metasurface reflector composed of deeply subwavelength nonperiodic inclusions arranged to impart the desired arbitrary phase distribution at the nanoscale. We obtain exciting and unique wave interaction properties, and we outline their potential applications at optical frequencies, demonstrating a novel photon management approach for broadband light absorption enhancement in thin-film solar cells, an efficient, low-dispersion integrated on-chip coupler, and a new concept for ultrathin optical carpet cloaks.

We explore a novel metasurface geometry, consisting of a deeply subwavelength patterned surface backed by a ground plane and able to control point-by-point the wave reflection and scattering. We show that a careful combination of the "collective response" of the metasurface inclusions together with the "local" nanoscale wave manipulation offered by their plasmonic properties enables efficient wave management with interesting implications for solar-cell technology, broadband on-chip in/out couplers, and ultrathin carpet cloaks. Our design is based on a single metareflector operating as a spatial phase modulator and the metasurface is efficiently realized by means of the combination of only two materials, forming conjoined optical nanoparticles as deeply subwavelength surface impedance units with broadband and angularly stable response. We show that, by introducing the desired surface impedance profile, we can generate an arbitrary scattering response using an ultrathin patterned layer, much simpler to realize than 3D inhomogeneous composites typically used to redirect electromagnetic waves based on gradient change in the refractive index. We use the nanocircuit paradigm to model and design nanoscale surface elements, and we show that this concept may have exciting applications in several novel optical devices, including efficiency and size.

More in general, the proposed concept opens exciting venues for light manipulation and control, offering a route for planarized, integrated nanostructures with broadband response and a relevant impact on integrated nanophotonic technology.