Detecting spatial coherence of light with planar metallic metamaterials

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We report on a discovery that homogeneous metallic non-diffracting metamaterials of a certain type respond differently to spatially coherent and incoherent light, enabling robust speckle-free discrimination between different degrees of coherence. The effect has no direct analogue in natural optical materials and may find applications in compact metadevices enhancing imaging, vision, detection, communication and metrology.

Over the last decade the concept of artificially engineered media (known as metamaterials) has revolutionized the field of optics, pushed the boundaries of microfabrication and stimulated the development of novel characterization techniques. The demonstration of anomalous reflection and refraction of light by metasurfaces opened another exciting chapter in optical engineering. Non-diffracting metasurfaces correspond to a class of low-dimensional (planar) metamaterials and are typically formed by optically thin metal films periodically patterned on a sub-wavelength scale. Despite their vanishing thickness metasurfaces interact strongly with light, which they can transmit, absorb or reflect without diffraction, effectively acting as optical media of zero dimension in the direction of light propagation. Metasurfaces are fully compatible with the existing fabrication processes adopted by CMOS technology, and offer unmatched flexibility in the design and control of light propagation, exhibiting exotic electromagnetic phenomena and replacing conventional bulk optical components.

Here we identify and investigate a class of trivial metallic planar metamaterials, which exhibit qualitatively different transmission spectra in the near-IR when illuminated with, respectively, spatially coherent and incoherent light (as shown in Figures 1a and 1b). The underlying strongly non-local response of the metasurfaces involves neither diffraction nor lattice resonances, which renders the reported effect as non-trivial. Previously unseen in metamaterials the effect appears to be robust and exceptionally strong (absolute difference in transmission exceeds 50%), and hence is immediately suitable for practical applications, such as optical metrology, imaging and communications.

Figure 1. Transmission spectra of planar metamaterials comprising periodic arrays of zigzag nano-wires (a) and nano-slits (b) measured under spatially coherent (crosses) and incoherent (lines) illumination respectively. The insets show fragments of SEM images of the respective metamaterials. Yellow box indicate the unit cell of the metamaterials. Double-headed arrows show the polarization of incident light. Scale bar corresponds to 1 μm.

Among the metasurfaces that have been found to discriminate between coherent and incoherent light are planar metamaterials featuring a continuous periodic zigzag pattern (see insets to Figures 1a and 1b). The metasurfaces that we consider here were designed to operate in the near-IR part of the spectrum and composed of arrays of continuous zigzag nano-wires, as well as their inversion, i.e., continuous zigzag nano-slits. Both the nano-wires and nano-slits had the width of about 80 nm and were milled with a focused ion beam in an 80 nm thick film of amorphous gold that had been sputtered on 0.5 mm thick fused-quartz substrate beforehand. The resulting patterns had the period of 660 nm along the zigzags and 520 nm across the zigzags. The fabricated samples had the area of 21.1 μm x 20.8 μm, which encompassed a total of 1280 zigzag periods.