High Transmission Plasmonic Metasurfaces in the Visible Band

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Primary CNF Tools Used: JEOL 9500

Abstract:

Metasurfaces are two-dimensional nanoantenna arrays that can control the propagation of light at will. In particular, plasmonic metasurfaces feature ultrathin thicknesses, ease of fabrication, field confinement beyond the diffraction limit, and ultrafast performances. However, the technological relevance of plasmonic metasurfaces operating in the transmission mode at optical frequencies is questionable due to their limited efficiency. The state-of-the-art efficiency of geometric plasmonic metasurfaces at visible and near-infrared frequencies, for example, is ≤ 10%. Here, we report a multipole-interference-based transmission-type geometric plasmonic metasurface with a polarization conversion efficiency that reaches 42.3% at 744 nm, over 400% increase over the state of the art. The efficiency is augmented by breaking the scattering symmetry due to simultaneously approaching the generalized Kerker condition for two orthogonal polarizations. In addition, the design of the metasurface proposed in this study introduces an air gap between the antennas and the surrounding media that confines the field within the gap, which mitigates the crosstalk between meta-atoms and minimizes metallic absorption.

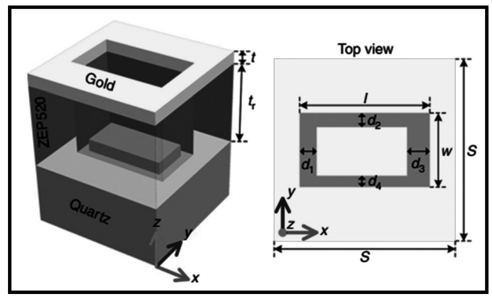

Figure 1: Schematic showing the designed multipole meta-atom, which consists of a gold nanoaperture and a gold nanorod separated by a perforated ZEP520 layer. In the meta-atom, S = 320 nm, l = 230 nm, w = 130 nm, t = 35 nm, and t_r = 180 nm. The multipole response of this meta-atom can be tuned by introducing an air gap between the nanorod and ZEP520 sidewalls, i.e., a noncomplementarity between the nanorod and the nanoaperture. The dimension of the air gap is denoted by $d_{1,2,3,4}$ in four sides.

Summary of Research:

In this work [1], we use multipole meta-atoms that support not only electric dipole and magnetic dipole but also an electric quadrupole and a magnetic quadrupole to construct an ideal half-wave plate. In multipole meta-atoms, it is possible to completely suppress backscattering for both orthogonal polarizations by satisfying the so-called generalized Kerker condition [2] and maintain the π-phase difference. We propose a multipole meta-atom design consisting of a metallic nanoaperture and a metallic nanorod separated by a perforated dielectric layer, as shown in Figure 1. The dimension of the nanorod and thus the multipole response can be modified by introducing a small air gap between the nanorod and the dielectric spacer separating adjacent meta-atoms, i.e. non-complementarity.

We also explore the advantages of the noncomplementary design of meta-atoms compared with complementary design, i.e. with no airgap between the nanorod and the nanoaperture. First, the introduction of non-complementarity is the key to engineering the multipole interference and enhancing the transmittance of light with cross-polarization ($T_{cross\text{-}CP}$), which, in most applications, is preferred for wavefront control of the transmitted light. As a result, we achieve an overall enhancement in the $T_{cross\text{-}CP}$ of the noncomplementary design. The peak efficiency is increased to 45.5% at a peak wavelength of 751 nm, i.e., $T_{cross\text{-}CP}$ is increased by > 10% compared with complementary design.

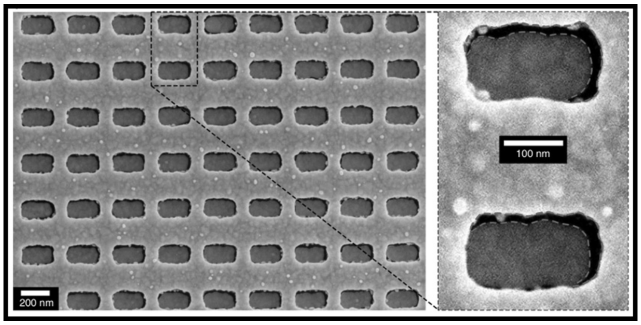

Figure 2: SEM image of a fabricated MPM and an enlarged view of two meta-atoms. The dashed lines mark the edges of the air gap.

Figure 3: Holography images at 750 nm for the noncomplementary design. (See pages vi-vii for full color version.)

Another evident advantage is the reduced near-field coupling between the meta-atoms. Both designs support good orientation-controlled phase responses. However, the $T_{cross\text{-}CP}$ amplitude of the complementary design significantly changes as a function of orientation angle of the meta-atom, while the noncomplementary meta-atom has higher and relatively flat amplitudes, representing reduced field coupling between meta-atoms.

Figure 2 shows scanning electron microscopy (SEM) images of the fabricated noncomplementary metallic plasmonic metasurfaces (MPM) using e-beam lithography on JEOL 9500 at CNF. The MPM has also been further tested on two applications, a beam deflector and a hologram, respectively. The beam deflector is realized by introducing a phase gradient on the surface, here the unit cell we used consists of eight subunits with an orientation step of 22.5°. The measured extinction ratio (ER) peaks at 7.8 dB at ~ 745 nm and exceeds 0 dB between 660 and 850 nm.

Both the peak transmission efficiency (E_p) and ER are significantly higher than the values of the current state-of-the-art MPMs ($E_p \leq 10\%$, ER ≤ 0 dB) in the visible and near-infrared regions in realizing various functionalities [3].

Another application that we demonstrate with the proposed design is a high efficiency hologram. Figure 3 shows experimental holography images in the far field at λ = 750 nm obtained from a noncomplementary design. The hologram efficiencies are measured to be 37%, which is better than those of the state-of-the-art GMs in the visible and near infrared regions [4]. The hologram is broadband as well, which shows holography images at various wavelengths.

Conclusions and Future Steps:

A significant increase in the transmission efficiency of plasmonic geometric metasurfaces is facilitated by tuning the multipole response of individual meta-atoms and by minimizing the crosstalk between meta-atoms. The maximum efficiency of the metasurfaces is on the long-wavelength side of the visible spectrum, 744 nm.

However, the demonstrated high efficiency exceeds that of the state-of-the-art over a wide wavelength range of 630-970 nm, i.e., in the red color range of the visible (visible covers 380-780 nm) and near-infrared regions. This concept and these techniques can be used for shorter visible wavelengths or longer-wavelength regions by tuning the dimensions of the meta-atom. This concept can be used for dielectric metasurfaces as well.

Furthermore, reflective-type metasurfaces can benefit from the generalized Kerker, no-front-scattering condition. On the other hand, perfect and selective light absorption can be achieved by eliminating both reflection and transmission, using the generalized Kerker approach.

In the future, even higher-order multipoles can also be included to improve the performance of MPMs [5].

References:

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