Optically-induced antiferromagnetic order in Mie-resonant dielectric metasurfaces

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Abstract: We study silicon-based metasurfaces with complex unit cells composed of Mie-resonant dielectric nanodisks and nanorings and observe experimentally a signature of optical response with a staggered structure of optically-induced magnetic dipole moments, associated with the so-called *optical antiferromagnetic order*.
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1. Introduction

The study of metasurfaces has attracted a lot of attention in photonics in the recent years, and the current trend is to employ high-index dielectric meta-atoms to create highly transparent, functional, and active metasurfaces [1-2]. Dielectric meta-atoms with high refractive index can support both electric and magnetic Mie resonances at optical frequencies, thus making the electromagnetic response of metasurfaces quite complicated. A natural question is how the basic properties of metamaterials and metasurfaces are defined by the near-field effects and how they can be engineered by changing their constituent elements, their geometry, and coupling between meta-atoms. These questions were addressed some years ago for plasmonics-based metasurfaces [3], and it has been found that the coupling effects in metallic structures resemble the effects of dipole−dipole interaction in solids.

Some years ago, it was shown that a metal-dielectric dimer structure composed of a split-ring resonator and a silicon nanosphere can exhibit a new type of optical magnetism, termed as *optical antiferromagnetic* (AFM) order, in contrast to the conventional parallel magnetic dipole moments that can be termed as ferromagnetic (FM) order. These predicted effects have never been observed in optics, whereas it was predicted theoretically that similar AFM order can be expected in anisotropic lattices composed of dielectric nanodisks and nanorings [4]. In this work, we fabricate and analyze two different types of all-dielectric metasurfaces with complex unit cells [see Figs. 1(a,b)] composed of Mie-resonant nanodisks and nanorings and observe experimentally optically-induced response with a signature of staggered magnetic dipole momenta, associated with the optical AFM ordering of magnetic dipoles.

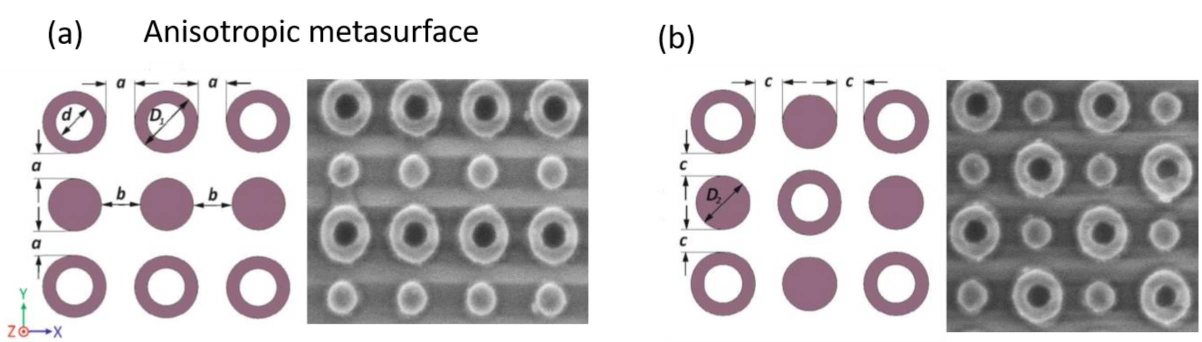

Fig. 1. Two types of silicon metasurfaces with a complex unit cell composed of dissimilar periodic lattices of resonant nanodisks and nanorings: (a) Structure and scanning electron micrograph of a metasurface composed of periodic rows of nanodisks and nanorings, termed as “asymmetric metasurface”. (b) Isotropic metasurface composed of a checkerboard lattice of nanoparticle quadrumers.

2. Results and Discussions

We follow the theoretical analysis of Ref. [4] and fabricate two types of dielectric metasurfaces. To fabricate the metasurface, we coated 300 nm thick hydrogenated amorphous silicon (a-Si: H) film onto SCHOTT-N-BK7 glass via plasma enhanced chemical vapor deposition (PECVD). Positive electron beam resist, ZEP520A was spin-coated on the film; then the pattern was formed using e-beam writing and subsequent development in ZED-N50. A 50 nm thick aluminium layer was evaporated on the sample, followed by a lift-off process by soaking in the resist remover (ZDMAC). The silicon film was etched in CHF_3 plasma with a small addition of SF_6 which leads to a highly anisotropic etching profile. Finally, the residual aluminum etch mask was removed using a wet etching solution.

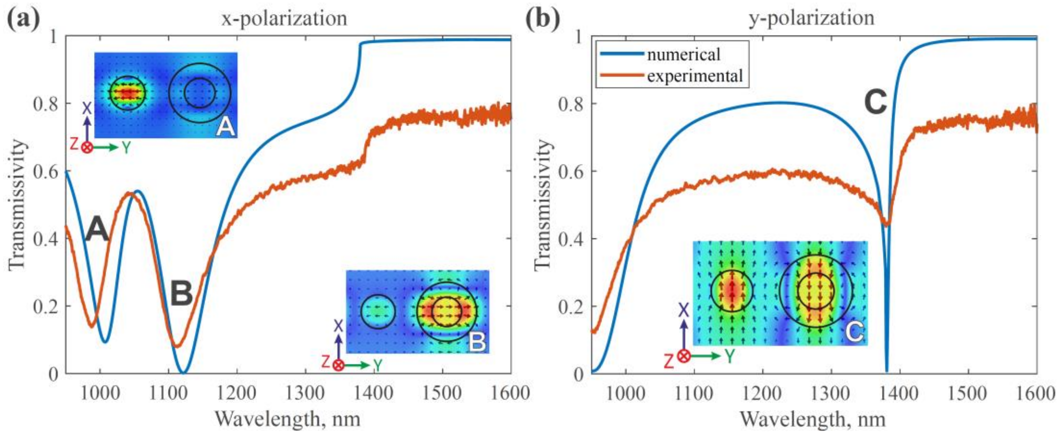

Fig. 2. Transmission spectra of dielectric metasurfaces with anisotropic arrangements of nanodisks and nanorings as shown in Fig 1(a), for two different polarizations of the external field: (a) x-polarization, and (b) y-polarization. For the x-polarization, two distinct magnetic dipole resonances are observed at 1010 nm and 1124 nm (mode A and mode B), as shown in the insets of (a). For the y-polarization, a hybrid response with the AFM ordering is observed at 1397 nm, as confirmed by the field structure shown in the inset.

Figures 2(a,b) show representative examples of the transmission spectra measured for dielectric metasurfaces with anisotropic arrangements of nanodisks and nanorings as shown in Fig. 1(a). The spectra are very different for two polarizations of the external field, and they reflect different types of resonances supported by the metasurfaces. For the x-polarization [see Fig 2(a)], two distinct magnetic dipole resonances are observed at 1010 nm and 1124 nm (mode A and mode B), as shown in the insets of (a). For the y-polarization [see Fig 2(b)], a hybrid response with the AFM ordering is observed at 1397 nm, as confirmed by the field structure shown in the inset.

3. Conclusions

We have demonstrated, for the first time to our knowledge, the effects of strong near-field coupling in Mie-resonant dielectric metasurfaces with a complex unit cell. We have considered two types of resonant dielectric meta-atoms (nanodisks and nanorings), and revealed that the overall optical response depends on the mode hybridization and nanoparticle ordering. In particular, we have observed an optically-induced response corresponding to a staggered structure of magnetic dipole moments, associated with the physics of *optical antiferromagnetism*.

4. Acknowledgements

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