Optical Anapole Mode with Planar Metamaterials

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1. Introduction

Natural toroidal molecules, such as biomolecules [1] and proteins [2], possess toroidal dipole moments that are hard to be detected, which leads to extensive studies of artificial toroidal materials. Metamaterials [3-4] are sub-wavelength artificial structures that can be specifically designed to manipulate the intensity of induced electromagnetic multidipoles. Recently, toroidal metamaterials [5-6] have been widely investigated to enhance toroidal dipole moments while the other multipoles are eliminated due to the spacial symmetry. However, to effectively excite a toroidal dipole, a specific excitation method is necessary since a closed-loop of induced magnetic dipoles in a toroidal metamaterial weakly interact with the external wave. This is a key issue that has to be carefully taken into account in existing toroidal experiments. Moreover, most of generated toroidal dipole moments are either aligned vertically to the substrate surface or embedded in a dielectric, leading to another constraint for further applications. In this paper, we present a novel design for a toroidal metamaterial with multilayered structures, which composed of a gold dumbbell-shaped aperture and a vertical split-ring resonator (VSRR). The induced toroidal dipoles show several advantages like free-standing and vertically oscillating configuration that are distinguishable from previously reported works. It is worth to mention that the non-radiating from the destructive interference from the toroidal and electric dipoles can also be generated in our proposed structures.

2. Results and discussion

As shown in Fig. 1(a), because the induced toroidal dipole moment is oscillating at the interface between metallic structure and free space, this design overcomes the challenge in detecting the scattering of the induced toroidal dipole and provides a possibility of coupling with other dipolar moments. Figure 1(b) shows the radiated power from decomposed multipoles. It can be found that the radiation intensity of electric and magnetic multipoles are much lower than that of the toroidal dipole around 1380 nm, verifying the generation of toroidal dipole moment. Also, the non-radiating anapole mode for the dynamic case is realized through such proposed toroidal metamaterials. The destructive interference between these two dipoles with identical radiation patterns leads to a resonant dip in the total scattering power spectrum as shown in Fig. 1(c). To our best knowledge, this is the first proof-of-concept demonstration of anapole mode though coupled plasmonic metamaterials which offers a promising way for the investigation of optical properties with complicated electromagnetic fields.

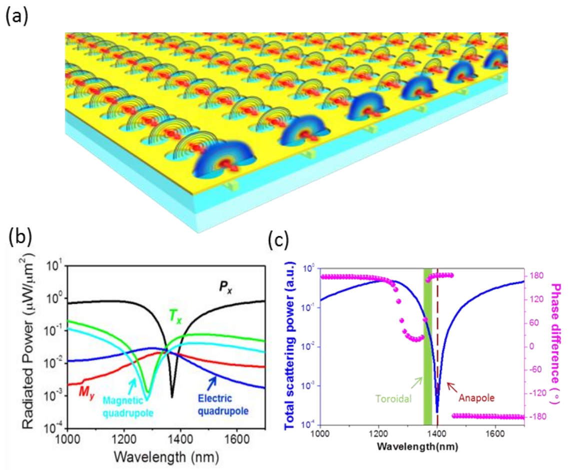

Fig. 1. (a) Schematic diagram of transverse toroidal dipoles generated by a plasmonic toroidal metamaterial. (b) Dispersion of radiated powers for various electromagnetic multipoles. T_x, P_x M_y represent the *x*-component of toroidal dipole, *x*-component of electric dipole and *y*-component of magnetic dipole, respectively. (c) Total scattering power (blue curve) and phase difference (magenta dots) from electric and toroidal dipoles. Green region and red dash line indicate the toroidal dominated mode and anapole mode respectively.

3. Conclusion

A novel plasmonic planar metamaterial which is able to generate a transverse toroidal dipole moment under normal illumination is presented in the optical region. In addition to the toroidal dipolar response, a non-radiating anapole mode resulting from the destructive interference between toroidal and electric dipoles is also observed. It is a real artificially designed and fabricated plasmonic metamaterials for the generation of both transverse toroidal dipole moments and associated anapole mode, and readily available for feasible applications.

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Reference

[1] R. Kovall *et. al.* Science 277, 1824-1827 (1997).
[2] A. A. Antson *et. al.* Nature 374, 693-700 (1995).
[3] D. R. Smith *et. al.* Science 305, 788-792 (2004).
[4] V. M. Shalaev *et. al.* Nature Photonics 1, 41-48 (2007).
[5] T. Kaelberer *et. al.* Science 330, 1510-1512 (2010).
[6] Z.-G. Dong *et. al.* Express 20, 13065-13070 (2012).