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1. 概要(Summary)

The toroidal dipole is a localized electromagnetic excitation differ from the normal magnetic and electric dipoles. Interference of radiating induced toroidal and electric dipoles leads to anapole, a non-radiating charge current configuration. [1] Here, we fabricate a quasi-planar plasmonic metamaterial, consisting of dumbbell aperture and vertical split-ring resonator, which shows transverse toroidal moment and resonant anapole behavior in the optical part of the spectrum upon a normal incident light excitation.

2. 実験(Experimental)

【利用した主な装置】

Electron Beam Lithography (Elionix ELS-130HM), Helicon Sputtering (ULVAC MPS-4000C1/HC1), SEM (JEOL JSM-6700FT), Dry etching (RIE-101iPH SAMCO)

【実験方法】

A Au nanorod array (size of 270 x 60 x 30 nm) was fabricated by electron beam lithography (EBL) and lift-off process. Two prongs (size of 60 x 60 x 30 nm) were fabricated on the Au nanorod by the second EBL exposure and lift-off process. A spin on glass (SOG) layer was subsequently spin-coated at 3000 rpm onto the EBL fabricated structure, and then it was baked on a hot plate for 3 min at 200 °C. Then, a 30-nm gold films was sputtered onto the SOG and spin coated ZEP-520A over the gold film. A third EBL and RIE dry etching was used to fabricate the dumbbell shaped holes array on the same area.

3. 結果と考察(Results and Discussion)

Figure 1a shows the schematic of the toroidal metamaterial structure. The toroidal metamaterial reported here is a multilayered structure containing a planar array of vertical split-ring resonators suspended in a dielectric medium and covered with a nanostructured gold film. Figure 1c-1e shows the top-view SEM images of the fabricated Au nanorods, nanorods with prongs and the dumbbell nanoholes array. The precisely engineered nanostructure enables to control the three-dimensional structure to tailor the toroidal dipole and the anapole modes at the wavelength of interested. Fig. 1b shows the

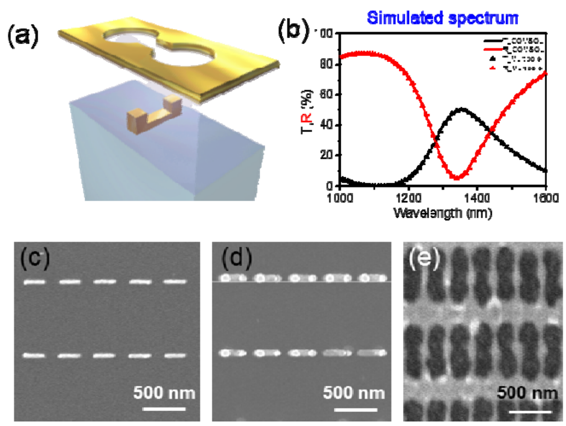

Figure 1. (a) Schematic of the anapole structure. (b) Simulated transmission and reflection spectra. (c)-(e) SEM images of the nanorod, nanorod with prongs and dumbbell nanoholes.

simulated transmission and reflection spectra. From the simulated transmission and reflection spectra, one can clearly observe a minimum far-field scattering intensity the wavelength of the anapole mode. The suppression of radiation losses offered by the multipole interference in the anapole modes could find many applications, such as surface enhanced Raman scattering (SERS).

4. その他・特記事項（Others）

・参考文献

[1] P. C. Wu, et al., *ACS Nano*, **2018**, 12, 1920–1927.

・共同研究者: X. Shi, J. Li, K. Ueno, Q. Sun, T. Oshikiri, and H. Misawa

5. 論文・学会発表（Publication/Presentation）

なし

6. 関連特許（Patent）

なし