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Plasmon hybridization in three-dimensional magnetic metamolecules

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1. Introduction

In the past decade, a number of interesting designs have been proposed to generate artificial magnetism at optical frequencies using plasmonic metamaterials, but owing to the planar configurations of typically fabricated metamolecules that make up the metamaterials, the magnetic response is mainly driven by the electric field of incident electromagnetic wave.In this work, we have fabricated 3D split-ring resonators (SRRs) [1] which allowed us to study how incident electromagnetic fields interact with these 3D SRRs and to reveal the plasmon coupling between closely spaced SRR dimers.

2. Discussions

Figure 1(a) shows the schematic of an array of 3D dimer (metamolecule) structures made of two 3D SRRs of different base rod lengths (L_1 = 170 nm and L_2 = 220 nm) that are placed in parallel along x-axis with their centers aligned on y-axis (the dimensions of this dimer sample is given in the caption of Fig. 1). The inset in figure 1(a) shows the SEM images (oblique views) of the gold SRR dimer sample with 50-nm gap separation fabricated on a glass (BK7) substrate.

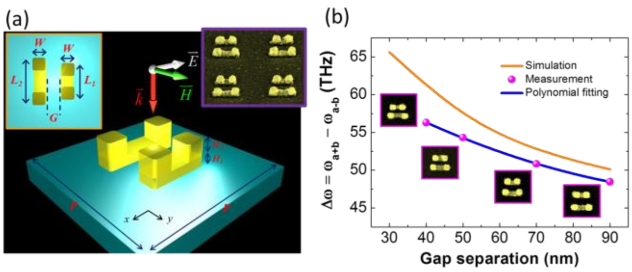

Figure 1: (a) Schematic diagrams of 3D SRR dimer unit cell. The 45° oblique and room in (inset) views for SEM micrographs from fabricated samples. (b) The bonding and anti-bonding splitting vs. the gap in a 3D SRR dimer. Orange line and magenta dots correspond to simulation and measurement results, respectively. Blue line: a second-order polynomial fitting for experimental results. Insets represent the corresponding SEM image with gap sizes G = 40, 50, 70 and 90 nm between SRRs (left to right).

We performed experimentally as well as numerically the transmittance spectra at different gap separations between SRRs where two transmittance dips (ω_{a+b}, ω_{a-b}) are well resolved and are associated with the surface plasmon resonances of the two SRRs of different sizes and their coupling. Figure 1(b) shows the simulation and measurement of resonance energy separation $\Delta\omega = \omega_{a+b} - \omega_{a-b}$ of the “anti-bonding” and “bonding” for the four samples with 3D SRR spacing from 40 to 90 nm under normal illumination. As the spacing G between the 3D SRRs reduces, $\Delta\omega$ increases rapidly with the decreasing G.

3. Conclusions

These 3D SRR metamolecules have the advantage of direct coupling to both the electric and magnetic components of the normal incident wave in comparison to their planar counterpart that only interacts with the electric field, resulting in stronger magnetic response. By conducting simulation and measurement of the optical transmittance, we have observed hybridization between the magnetic plasmon modes associated with constituent 3D SRRs in a metamolecule where bonding and anti-bonding modes emerged. We have found that the energy separation between the bonding and anti-bonding modes in a metamolecule depends on the gap separation in 3D SRR dimers. The tuning capability enabled by the magnetic plasmon mode coupling can be explored for developing frequency selective functional devices.

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References

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