Coherent coupling control of meta-resonance in planar metamaterials

Jeong Weon Wu*[1], J. H. Woo[1], E. S. Kim[1], Boyoung Kang[1], E. Y. Choi[1], J. Kim[1], Y. U. Lee[1], Tae Y. Hong[2], Jae H. Kim[2]
[1] *Physics Department and Quantum Metamaterial Research Center*
Ewha Womans Unversity, Seoul 120-750, Korea,
[2] *Physics Department, Yonsei University, Seoul 120-749, Korea*
**E-mail:jwwu@ewha.ac.kr*

1. Introduction

Control of the coherent coupling in plasmonic resonances is an important means to tailor the resonance spectral shape, which naturally extends to metamaterials. By controlling the coupling between dipolar and quadrupolar excitations in 3-D metamaterial, electromagnetic induced transparency (EIT) has been demonstrated. A coherent coupling between the superradiant and subradiant plasmon modes allowed the observation of Fano resonances in a symmetrybroken concentric disk-ring and dolmen-style slab metamaterials consisting of metallic nanostructures. Another approach to control coherent coupling is to introduce a superlattice structure of metaparticles, where the in-plane coherent coupling between metaparticles is exploited to pursue novel properties. Examples include a dual-band metamaterial superlattice composed of two different sized symmetric split ring resonators, a wave-length dependent optical wave plate based on asymmetric superlattice, a resonance sharpening in supercell with four split ring resonators, and an EIT-like induced transparency in the two asymmetric split ring resonator superlattice. In this work, we look at the metatmaterial superlattice where the dissymmetry is brought in such that symmetric double-split ring resonator (DSRR) are asymmetrically orientated in a square lattice, in contrast with the metamaterial where asymmetric DSRRs are symmetrically oriented in a square lattice. Furthermore, a superlattice structure where the orientation of symmetric DSRR is symmetrically alternated is studied to investigate the temperature dependent quality factor of closed mode.

2. Fabrication and Experiment

The metaparticle for construction of superlattice is a DSRR, with inner radius 14μm and outer radius 18μm. The width of circle line 4μm. The symmetric gap openings of 20◦ arc occur between −10◦ and +10◦ and between +170◦ and +190◦. The geometric structure of DSRR metaparticles is highly symmetric, possessing the point group D_{2h} symmetry. Fig.1 shows the optical microscope images of symmetric and asymmetric metamaterials.

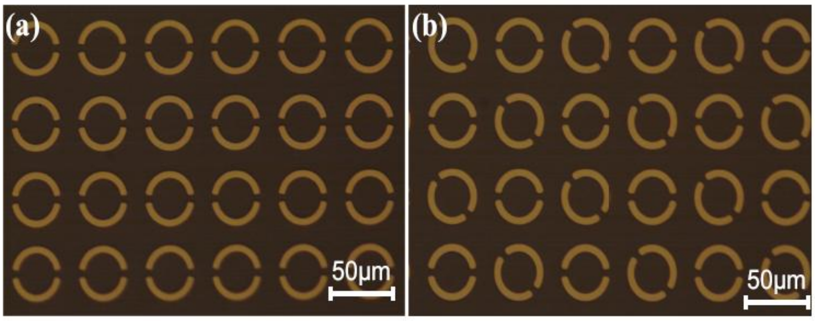

Fig. 1. Optical microscope images of (a) symmetric and (b) asymmetric metamaterials

Another example is a symmetric metamaterial superlattice consisting of symmetric DSRRS oriented symmetrically with a non-zero inclination angle with respect to x-axis. Fig.2 shows schematic drawings of grating wavy strip and symmetric metamaterial. The structure is different from that shown in Fig.1 in the sense that the superlattice is symmetric with respect to x- and y- axis.

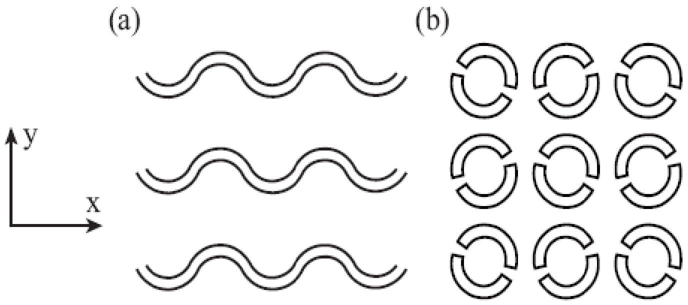

Fig. 2. Schematic drawings of (a) grating-wavy-strip and (b) symmetric metamaterial

Time-domain terahertz transmission measurements were carried out with a TeraView TPS Spectra 3000 Spectrometer. The time-domain pulse duration is about 2 ps, leading to the accessible spectral range of 0.1-3 THz (3-100cm-1). The incident light from emitter is almost linearly polarized. The low temperature measurements were performed by using temperature controllable cryostat at resolution 1.0cm-1. Liquid helium was introduced to vacuum chamber near the metamaterial superlattice to investigate the changes in transmission spectra as a function of temperature.

3. Results

Fig. 3 shows THz transmission spectra of the metamaterial superlattice for different polarization directions of the incident light, 0° and 90°. We find that a high Q meta-resonance appears when the incident polarization is 90°. The counter-flowing current densities cancel each other among the nearest-neighbors to suppress the radiative damping. The cryogenic temperature measurement shows that Joule damping in meta-particle can be reduced by lowering temperature, and the amount of reduction is found to be dependent on whether the mode is open or closed.

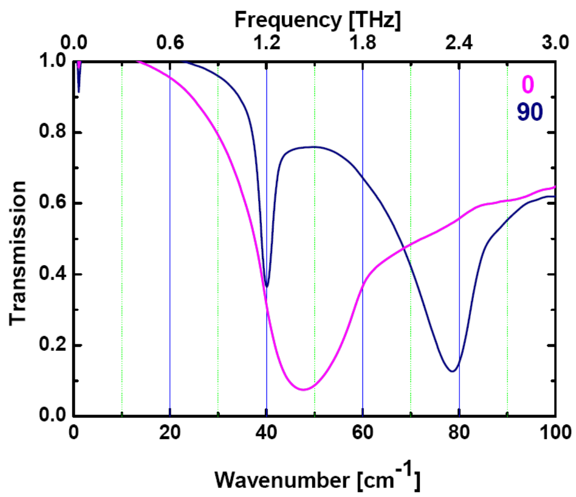

Fig.3. Transmission spectra of symmetric metamaterial with the closed mode appearing at 90° polarization

References

[1] Boyoung Kang, E. Choi, Hyun-Hee Lee, E.S. Kim, J. H. Woo, J. Kim, Tae Y. Hong, Jae H. Kim, and J.W. Wu, “Polarization angle control of coherent coupling in metamaterial superlattice for closed mode excitation”, Opt. Express 18, 11552 (2010).

[2] J. H. Woo, E. S. Kim, E. Choi, Boyoung Kang, Hyun-Hee Lee, J. Kim, Y. U. Lee, Tae Y. Hong, Jae H. Kim, and J. W. Wu, “Cryogenic temperature measurement of THz meta-resonance in symmetric metamaterial superlattice”, Opt. Express 19, 4384 (2011).