current densities are plotted for the closed mode excitation (67.5°) and the open mode excitation (157.5°).

For the polarization angle of 67.5° and resonance frequency ω_C, Figs. 5(a) and 5(b) show that the current densities J_x and J_y of 0°- and 135°-particles are in the opposite direction. As shown in the schematics of current density, Fig. 5(c), the current densities inside the DSRR are in the opposite direction among the nearest-neighbors. The counter-flowing current densities cancel each other resulting in the excitation of the closed mode. For the polarization angle of 157.5° and resonance frequency ω_O^L, Figs. 6(a) and 6(b) show that the current densities J_x and J_y of 0°- and 135°-particles are in the same direction. As shown in the schematics of current density, Fig. 6(c), the current densities inside the DSRR are in the same direction among the nearest-neighbors. The co-flowing current densities do not cancel each other resulting in the excitation of the open mode.

Even though the underlying mechanism for closed mode excitation, i.e., current flow cancelation, is identical to what happens in the metamaterial where asymmetric DSSRRs are symmetrically oriented in a square lattice, the current flow cancelation takes place among the nearest neighbors in the metamaterial superlattice, not inside the individual metaparticles. Compare Fig. 5 and Fig. 6 with Fig. 2 and Fig. 3 of Ref. [9].

The damping of a plasmon resonance, γ, consists of the Drude damping, γ_D, and the radiative damping, γ_R. That is, $\gamma = \gamma_D + \gamma_R$ [9, 14, 20]. While the Drude damping is determined intrinsically by the composition and substrate of metamaterial, the radiative damping is a function of the polarization angle in the metamaterial superlattice. At the polarization angle 67.5°, the maximum cancelation of anti-symmetric current flows takes place, leading to the minimum radiative damping resulting in the highest Q-factor. In the open modes ω_O^H and ω_O^L, the oscillator couples to the free-space decay channel resulting in a low Q resonance, while a coherent coupling among nearest-neighboring 0°- and 135°-particles significantly suppresses the free-space decay in the closed mode ω_C with an enhanced Q-factor. This is reminiscent of a recent report on the suppression of radiation losses in periodic arrays in coherent metamaterials [21].

In the work of Al-Naib *et al.* [22], miniaturized asymmetric single split resonators were introduced to enable asymmetric current flows at the individual asymmetric resonator in the GHz regime, enhancing Q-factor compared to symmetric single split resonators. In contrast, the excitation of closed mode in the metamaterial superlattice reported here is from the cancelation of current flows among the nearest neighboring double-split ring resonators through a coherent coupling which can be controlled by the incident polarization angle.

5. Summary

In summary, a polarization angle tuning of coherent coupling is demonstrated in the metamaterial superlattice by resorting to the closed mode excitation. Alternately oriented double-spit ring resonators superlattice structure permits the angular control of the amount of anti-symmetric current flows among the nearest-neighboring metaparticles. The metamaterial superlattice will be a useful tool for angle-selective enhancement of local fields, for example, in the study of the structure edges of graphenes. The future works will include the investigation of the polarization angle control of EIT in metamaterial superlattices.

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