Hybrid coupling and coherent perfect absorption in ultra-thin bilayer metamaterials

Wei Tan[1,*], Caihong Zhang[2], and Biaobing Jin[2]
[1]Microsystem &Terahertz Research Center, China Academy of Engineering Physics, Chengdu 610299, China
[2]Research Institute of Superconductor Electronics (RISE), Nanjing University, Nanjing 210093, China

* Email: tanwei@mtrc.ac.cn

Photonic analogue of quantum interference is an interesting topic since the demonstration of electromagnetically induced transparency (EIT) behavior in metamaterials. In a well-defined EIT configuration, a bright resonator is strongly coupled to a dark resonator that has almost equal resonance frequency, where the near-field coupling leading to a transparency window within two split transmission dips. Another type is the dressed-state picture, where two detuned resonant states interference via only far-field (indirect) interactions. Similar spectra occur, but the transmission dips respectively correspond to the two individual resonators, without energy-level splitting.

This study focuses on ultra-thin bilayer metamaterials, where both near- and far-field interactions play important roles at the deep subwavelength scale. We establish a hybrid coupling model within the framework of coupled mode theory. It shows clearly the different contributions of near- and far-field couplings to electromagnetic responses: the former is only responsible for the energy level splitting, while the latter mainly reshapes the profile of the resonance spectra. The configuration composed of two closely separated identical resonators is a typical hybrid-coupled system, whose spectrum exhibits a very sharp subradiant resonance within the envelope of a superradiant resonance and interference between them leads to a sharp Fano resonance. By adjusting the near- and far-field couplings, the Fano resonance can be altered to symmetric EIT-lineshape, and vice versa. We show that the previous EIT model and dressed-state model can be considered as special cases of the hybrid coupling model. It provides more flexible ways of tailoring electromagnetic responses at the deep subwavelength scale.

In addition, we investigate the ultrathin bilayer metamaterials under two-coherent-beam illuminations. We demonstrate that the subradiant mode can be selectively excited via antisymmetric-incident beams, while the superradiant mode is highly suppressed, attributing to their different mode symmetry. A sharp coherent perfect absorption (CPA) peak with well-defined Lorentzian lineshape is achieved under critical conditions, relating to the subradiant mode. The peak frequency can be tuned by tailoring the near-field coupling, which is corresponding to the energy-level splitting. The physical insight is well described by the hybrid coupling model. Ultrathin bilayer terahertz metamaterials with flexible polyimide substrate and interlayer are fabricated, and tested by THz time domain spectroscopy. The measurements show very good agreement with the theoretical and numerical results. This work provides a method of how to extract narrow subradiant resonance from an asymmetric Fano lineshape, which may enlighten the way for selective mode excitation via coherent control.

This work was supported by Science Challenging Program (SCP) of China under Grant No. TZ2017003-2 and the National Natural Science Foundation of China under Grant No. 11504346, 61501219, 61671234.