Tuning Fano resonances in a SRR based metamaterial

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Abstract

Narrow Fano resonances are generated in a metamaterial consisting of coupled split-ring resonators (SRRs). We show that their asymmetric lineshape can be tuned dramatically by controlling the coupling between the symmetric and antisymmetric eigenmode of the metamaterial.

1. Introduction

For a long time the observation of Fano resonances has been a unique feature in interacting quantum systems. A particular prominent example of a quantum phenomena where Fano resonances occur is electromagnetic induced transparency (EIT) (see Fig. 1(a)). The coherent coupling of a broad and a narrow resonance leads to quantum interference and can reduce light absorption over a narrow spectral region. The asymmetric line shape of the corresponding Fano-type resonance depends on the coupling constant κ between the two states. Lately, analogous Fano resonances and EIT-behavior have also been discovered in metamaterials and plasmonic nanostructures [1],[2]. Here we demonstrate dramatic tuning of the Fano profile in a double SRR metamaterial by changing the vertical separation between the two resonators in a unit cell.

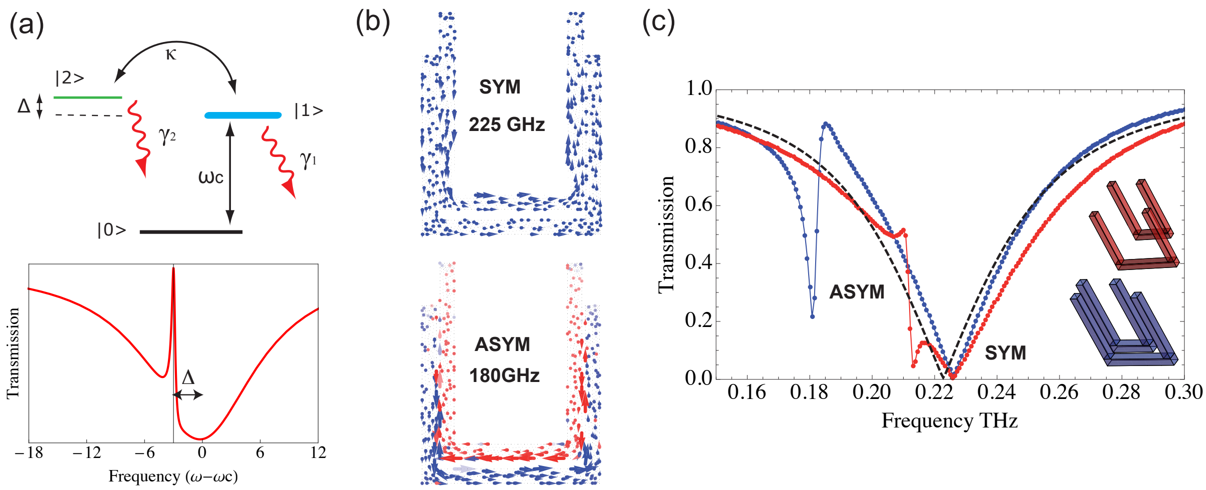

Fig. 1: (a) Schematic figure of an EIT system (top) with the corresponding absorption profile (bottom). (b) Current density plots of two SRRs at the two resonant frequencies (marked in (c)). (c) Simulated transmission spectra for a single SRR (dashed black) and two coupled SRRs with distance z=0 (blue) and z=50 μm (red).

2. Tuning the Fano resonance

For a metamaterial consisting of unit cells containing two closely stacked SRRs, with the same overall length (l=600 μm), coupling of electric and magnetic near fields leads to the splitting of their degenerate fundamental LC-resonance into a symmetric and anti-symmetric eigenmode. Figure 1(c) shows simulated transmission spectra (incident E-field polarization along the x-axis) for a single SRR (black dashed line) and a double-SRR with vertical spacing z=0 (blue line) with the associated minima at 225 GHz for the symmetric and 180 GHz for the antisymmetric mode. The corresponding current densities are shown in Figure 1(b). The symmetric mode with both SRRs oscillating in-phase is associated with a large collective dipole moment and therefore corresponds to a broad dipole resonance (bright mode). The sharp asymmetric mode (dark mode) has vanishing resulting dipole moment since both SRRs oscillate out-of-phase [3]. This dark resonance can only be excited due to an asymmetry in the system, in our case the slightly different shape of the SRRs. Interference between bright and dark mode leads to the formation of an asymmetric Fano transmission profile associated with a high transparency peak and steep normal dispersion.

Strikingly, the asymmetry of the Fano profile can be dramatically tuned from positive to negative slope by changing the vertical distance between the two SRRs as shown in Figure 1(c). Here, the blue curve corresponds to distance z=0 and the red curve to z=50 μm. As we will show, variation of the spacing changes the coupling between the two modes due to the formation of a strong magnetic field between the vertically separated SRRs, which may couple to the magnetic component of the THz excitation. Strength, width and position of the Fano Resonance can further be tuned by changing other geometric parameters, such as the lattice constant, width and shape of the SRRs.

3. First experimental results

For experimental verification of the effect similar arrays of metallic SRRs were fabricated by inkjet printing and by conventional photolithography with subsequent metal etching, see Figure 2 (a). Sample 1 consist of an array of double SRRs with the same length (600 μm), thickness of 40 μm and lattice constant g_x=g_y= 420 μm, the vertical spacing is z=0. In Sample 2 the array is composed of two identical SRRs, with vertical spacing of z=50 μm, thickness 60 μm and lattice constant is g_x=g_y= 350 μm.

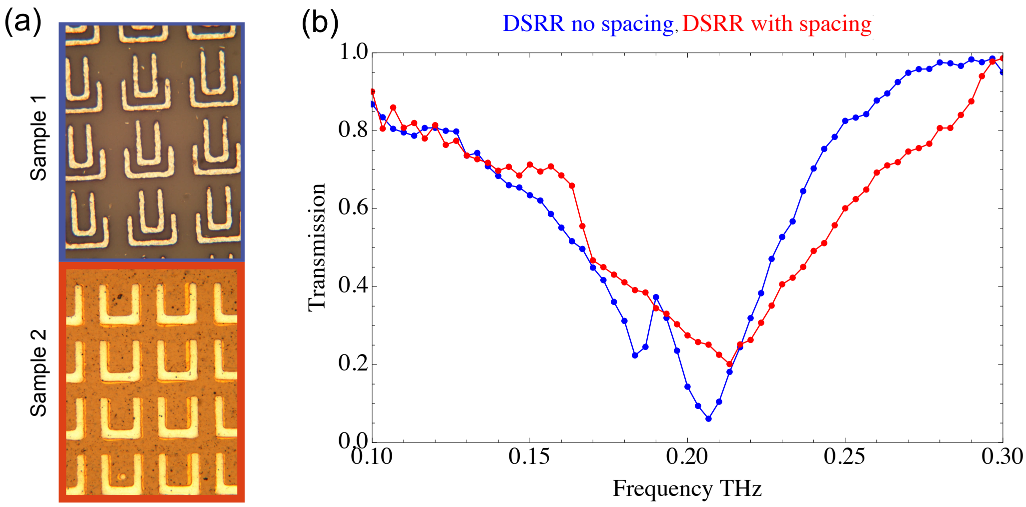

Fig. 2: (a) Microscope picture of the two samples. Sample 1: etched Copper SRRs on 50 μm Teflon substrate. Sample 2: Inkjet printed gold SRRs on both sides of a 50 μm Polyimide substrate. (b) Measured transmission spectra of the two double SRR samples. Blue line corresponds to Sample 1, with no vertical spacing between the SRRs, red line corresponds to Sample 2 with vertical spacing z=50 μm.

The corresponding transmission spectra of the two samples (Fig. 2 (b)) were measured with a common Terahertz Time-Domain-Spectroscopy (TDS) setup [4]. The characteristic behavior in the simulation can also be identified in the experiment, even though sharp features can not be resolved. For the first Sample (blue line) the Fano resonance occurs at about 190 GHz, but the asymmetric profile and position (now 160 GHz) is changed when the formation of magnetic field is allowed through the spacing between the SRRs (red line). The stronger red shift compared to the simulation could be due to the influence of other geometric parameters such as the lattice constant or shape of the SRRs.

4. Conclusion

In summary, we demonstrate Fano resonances and EIT-like behavior in a THz metamaterial consisting of two coupled SRRs within a unit cell. By changing the vertical spacing between the SRRs and thereby increasing the coupling between the modes we are able to tune the asymmetry of the Fano resonance profile. This tunability of Fano resonances in THz metamaterials, might have promising applications in sensing, focussing or slow light devices.

References

[1] B. Lukyanchuk, N. Zheludev, S. A. Maier, N.J. Halas, P. Nordlander, H. Giessen and C. Chong, The Fano resonance in plasmonic nanostructures and metamaterials, *Nat. Mat,* vol. 9, 707, 2010.

[2] H. Merbold, A. Bitzer and T. Feurer, Near-field investigation of induced transparency in similarly oriented double split-ring resonators, *Opt. Lett.,* vol. 36, no. 9, 1683, 2011.

[3] V. Fedotov,M. Rose, S. Prosvirnin, N.Papasimakis and N. Zheludev, Sharp Trapped-Mode Resonances in Planar Metamaterials with a Broken Structural Symmetry, *Phys. Rev. Lett,* vol. 99, no. 14, 147401, 2007.

[4] D. Grischkowsky, S.Keiding, M. van Exter and C. Fattinger, Far-infrared time-domain spectroscopy with terahertz beams of dielectrics and semiconductors , *J. Opt. Soc. Am. B,* vol. 7, no. 10, pp.2006, 1990.