Radiative coupling in metamaterial arrays

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Summary

We show that a resonant response with very high quality factors can be achieved in periodic metamaterials by radiatively coupling their structural elements. The coupling is mediated by lattice modes and can be efficiently controlled by tuning the lattice periodicity. Using a recently developed terahertz (THz) near-field imaging technique and conventional far-field spectroscopy together with numerical simulations we pinpoint the underlying mechanisms. In the strong coupling regimes we identify avoided crossings between the plasmonic eigenmodes and the diffractive lattice modes.

Introduction

Metamaterials have recently attracted considerable interest due to their potential application for perfect lensing, invisibility cloaking, or as negative refractive index material. These artificially designed media typically consist of periodically arranged metallic structures, which show a strong resonant response to an incident electromagnetic field. The ability to customize metamaterials requires control over the strength, linewidth and spectral position of their resonances. A powerful concept for tailoring metamaterial resonances uses coupling between individual eigenmodes of closely spaced structures such as adjacent or laterally stacked split ring resonators (SRRs). Here we study radiative coupling between the sub-units in a periodic metamaterial in detail. We demonstrate that by choosing appropriate lattice geometries a remarkable increase of the quality factors of the metamaterial resonances can be achieved.

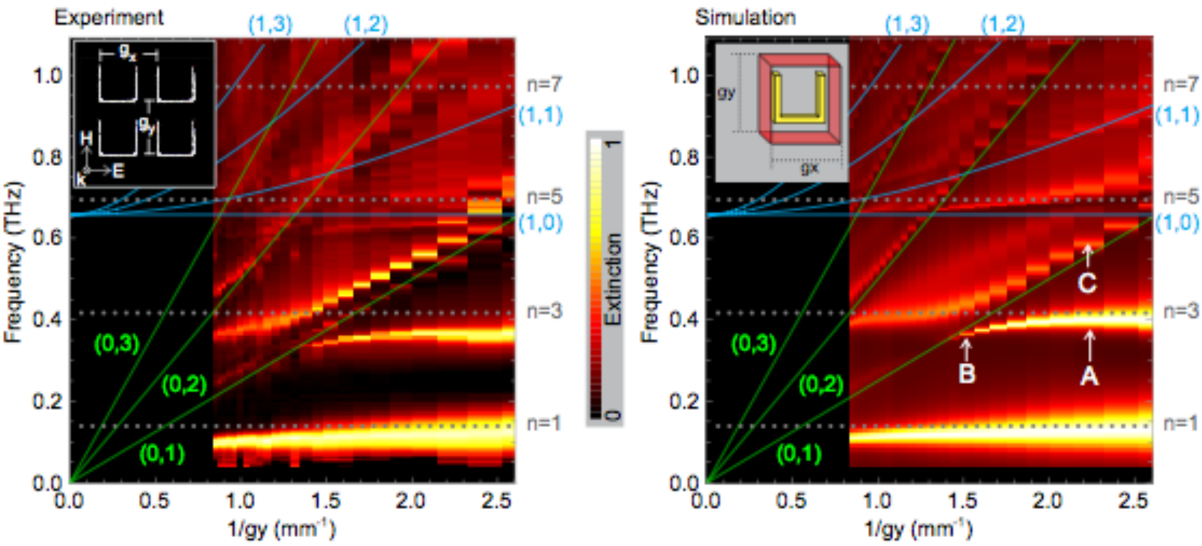

Fig. 1: (left) Dispersion diagram obtained from the measured transmission spectra. In the measurement the lattice constant gy is changed in steps from 380 to 1200 µm while gx =380 µm is constant. Plasmonic structure resonances are indicated by dotted horizontal lines (gray) and lattice modes by solid lines (green, blue). (right) Dispersion diagram obtained from an FEM Simulation of the spectra.

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Discussion

The plasmonic eigenmodes of SRRs can be excited whenever the wire length of the unfolded SRR approaches odd multiples of half the wavelength. Even eigenmodes are forbidden due to the asymmetry of the electric potential provided by the incident field. The fundamental eigenmode of the SRR (n=1) is associated with a circular current oscillating around the ring inducing a magnetic dipole (LC-resonance). The next higher mode corresponds to the formation of an electric quadrupole (n=3). In addition to the plasmonic eigenmodes lattice modes can be excited in an array of split-ring-resonators. Here, constructive interference of the radiation, which is scattered by the periodic lattice, causes abrupt changes in transmission. These spectrally shifting lattice modes are clearly distinguishable from the almost stationary plasmonic modes.

In order to study the effect of lattice diffraction on the plasmonic eigenmodes we have fabricated a set of rectangular arrays of SRRs in which the lattice periodicity in y-direction changes in 24 steps from gy = 380 to 1200 µm, while the x-periodicity is constant at gx = 380 µm. Their transmission has been characterized by a conventional far-field THz time-domain spectrometer and the spectral evolution is plotted in Fig. 1 as a function of the reciprocal lattice constant 1/gy. In these dispersion diagrams the dotted horizontal lines mark the spectral position of the plasmonic eigenmodes of the individual SRR. The solid lines indicate the calculated lattice excitations. Basically all expected features are observed in the measurements. Of particular interest are the regions where the plasmonic structure and the diffractive lattice modes meet. At the intersection of the n=3 eigenmode with the (0,1) lattice resonance, for example, a pronounced anti-crossing indicates strong interaction between the modes. A similar but weaker avoided crossing is observed between the structure resonance n=5. In addition, the plasmonic eigenmodes sharpen significantly at the crossing points leading to extremely high quality factors of the resonances. Both effects are explained in terms of radiative coupling between the individual elements mediated by the lattice modes [1]

Conclusion

In summary, we have shown that changing the lattice periodicity in metamaterial arrays allows to control coupling between the ”meta-atoms” via their radiated fields. For appropriate chosen lattice periodicities strong radiative coupling causes avoided crossings in the transmission spectrum and leads to large quality factors of the resonances. Our approach provides a novel route to shape resonances in metamaterials and is scalable in frequency. These findings pave the way for optimized design of metamaterials.

References

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