THz near-field microscopy of complementary metamaterial structures: Babinet's Principle

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Summary

We apply terahertz (THz) near-field microscopy to investigate the resonant response of plain and complementary split-ring resonators. The field maps show that at the resonances the measured electric near-fields of the structures correspond to the magnetic near-fields of their complements, as also predicted by recent numerical simulations in consistence with Babinet's principle.

Introduction

Artificial metamaterials with tailored electromagnetic properties have been a subject of growing interest in recent years. Most proposed metamaterials are composed of metallic split-ring resonators (SRR), or similar structures, which respond to an incident electromagnetic field. An alternative approach for the design of metamaterials is based on Babinet's principle and uses complementary structures [1], in particular complementary split ring resonators (CSRR) as structural subunits. So far, these structures have been mostly characterized by far-field measurements, which do not provide direct insight into the formation and dynamics of the microscopic fields responsible for the metamaterial's characteristic response. An experimental characterization of the involved electric and in particular the magnetic near-fields remains highly challenging and current studies rely mostly on numerical simulations. Only recently, THz-near-filed imaging methods have been developed [2, 3] providing spatially resolved measurements of the amplitude, phase and polarization of the electric fields from which also the microscopic magnetic near-field signatures can be extracted. Here, we investigate the resonant behavior of SRRs and CSRRs by THz time-domain spectroscopy and by THz near-field microscopy.

Discussion

Babinet's principle states, that when a structure (SRR) is illuminated by an electromagnetic wave it shows a complementary scattering response as its complementary structure (CSRR) illuminated by a complementary incident field. Here, the complementarity of the incident waves is established by a rotation of the polarizations by 90°. In the far-field the complementary response manifests in the fact that the transmission spectrum of an SRR corresponds to the reflection spectrum of a CSRR, and vice versa [1]. But how is the complementarity expressed in the near-field?

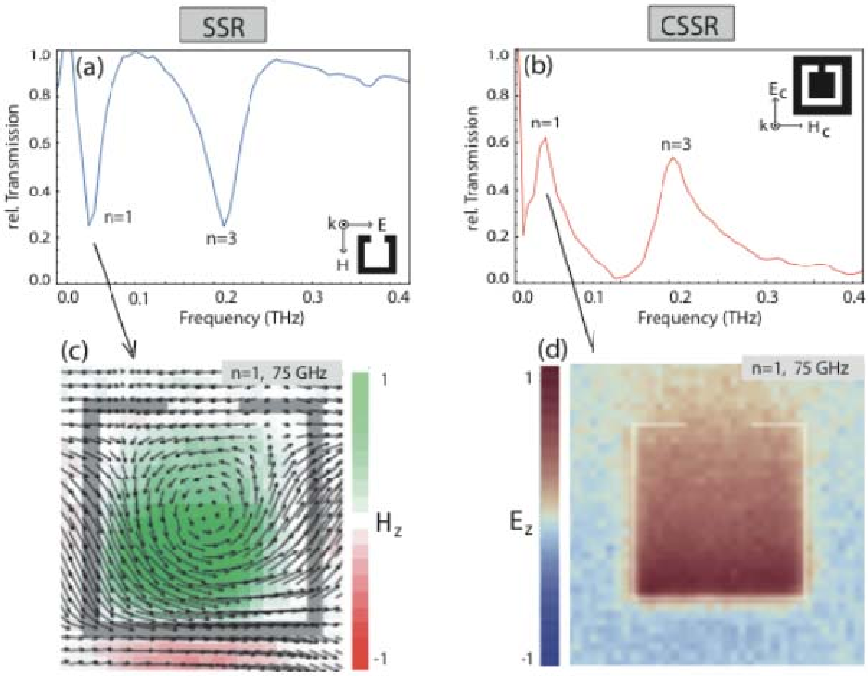

Fig. 1: Transmission spectrum of a square array of (a) SSRs and (b) CSRRs. (c) Measured near-field map of an SRR at its fundamental resonance showing the in-plane electric (arrows) and out-of-plane magnetic field (color code). (d) Measured out-of-plane electric field component (color code) of a corresponding CSRR.

First, the far-field transmission spectra of the SRR and the CSRR have been characterized under normal incidence using a conventional THz time-domain spectrometer, showing the individual resonances of the structures as shown in Fig. 1 (a) and (b). THz near-field microscopy enables us to measure the full vectorial electric field E(x, y, z) behind the SRR and the CSRR [2,3], from which the magnetic field vectors can be extracted using Maxwell's equations. In Fig. 1 (c) the measured in-plane electric field vectors (arrows) and the out-of-plane magnetic field distribution (colors) is plotted for a SRR at its fundamental resonance. We find that the magnetic field pattern (Hz) agrees very well with the measured out-of-plane electric field component (Ez) of the corresponding CSRR (Fig. 1 (d)). As we will show, this complementarity of the near-fields is a direct consequence of Babinet's principle.

Conclusion

In summary we have investigated plain and complementary split ring resonators by THz time domain spectroscopy and by THz near-field microscopy. Our results are in agreement with proposed theories and recent numerical simulations and fully confirm the predictions from Babinet's principle.

References

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