Terahertz response of a metamaterial consisting of 3-D microcoils

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Summary

In this paper we use terahertz time-domain spectroscopy and numerical simulations to investigate the response of a metamaterial consisting of subwavelength-sized 3-D micro coils fabricated by an automated wire bonding technique. We demonstrate that periodic arrays of the coils show a strong electromagnetic response, exhibiting characteristic resonances in their far-field transmission spectrum.

Introduction

Since the first experimental demonstrations of metamaterials in the microwave regime, progress in structure miniaturization extended the spectral range for metamaterial applications over terahertz and infrared to optical frequencies. Located at the interface between electronic and optical regimes, the terahertz (THz) range is particularly suited for the detailed investigation of metamaterial properties. Due to the moderate structure sizes at THz wavelengths and the availability of powerful characterization techniques, such as broadband and phase-resolved spectroscopy [1] or nearfield microscopy [2], the THz regime provides the ideal testbed for investigating novel metamaterial structure and designs. The inherent scalability of metamaterial structure allows the transfer of concepts to other frequencies. Here, we investigate the THz response of a novel metamaterial consisting of arrays of 3-dimensonal micro coils, both, by THz spectroscopy and by FEM-based simulations.

Experiment

The coils have been fabricated by winding a wire around dielectric posts (SU-8), which have been deposited onto a glass substrate, by an automated wire bonder [3]. The diameter of the posts is 200 µm. The wire ends are contacted to two parallel metallic pads (see Fig. 1 (a)). Two sets of coils have been processed, one with half and one with one-and-a-half windings. In a simplified picture the individual structures can be viewed as small L-C resonator circuits consisting of an inductance provided by the coil and a capacitance provided by the pads.

The far-field transmission spectrum of an array of coils with 1.5 windings shown in Fig. 1 (b) exhibits two distinct resonances (I and II). In the experimental configuration, as shown in the inset to Fig. 1 (a), with the magnetic field orthogonal to the coil axes, the structures can only be excited by the incident electric field. Furthermore, due to the polarization of the electric field parallel to the gap between the electrodes, only eigenmodes can be excited, where the current density standing wave has an odd number of nodes along the metallic wire [2].

Simulation

In order to analyze the characteristic of the individual eigenmodes we have performed numerical simulations using a commercial FEM package (COMSOL). Here a single

ISBN 978-3-00-030509-2

structure consisting of substrate, post, coil and pads has been placed in the center of a 3-D simulation volume with scattering boundary conditions on the four sides as shown in the inset of Fig. 1(c). A THz transient was incident from the top. For obtaining the transmission spectrum in Fig. 1(b) the transmitted time-dependent field has been sampled on the bottom, at some distance, i.e. in the far-field, and was Fourier-transformed into the frequency domain. The characteristic transmission spectrum observed in the experiment is well reproduced by the simulation.

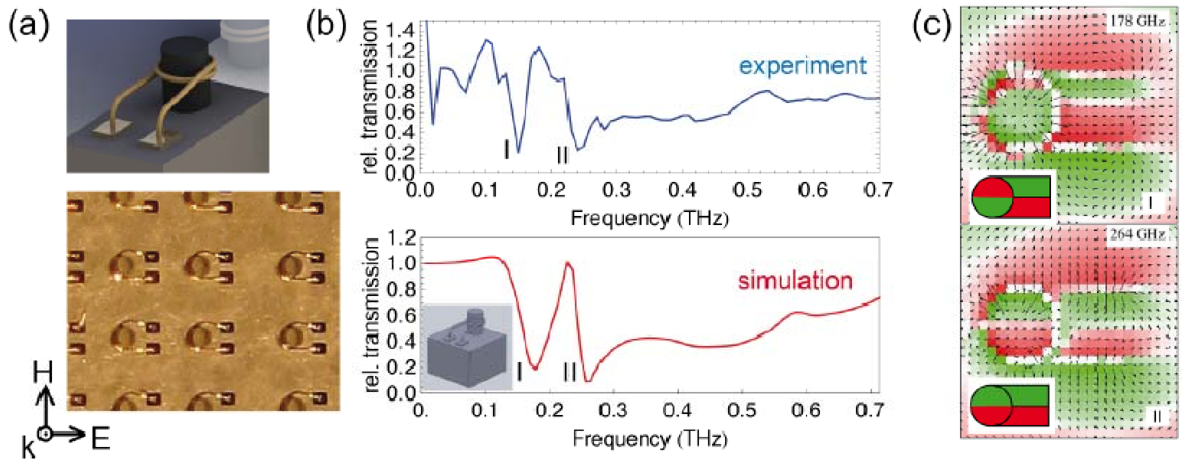

Fig. 1: (a) Rendered illustration and microscope image of a single and an array of micro coils. (b) Measured and simulated far-field transmission spectra of the micro coil array. (c) Simulated in-plane electric (arrows) and out-of-plane magnetic (colors) near-fields for mode I and II.

In addition electric and magnetic near-fields of the structures have also been extracted from the simulation as shown in Fig. 1(c). To a first approximation, the two resonances can be understood as the result of a hybridization of the fundamental eigenmodes of a simple ring and a half-loop. As illustrated in the insets, for mode II the magnetic field in the ring and the loop have similar orientation, whereas it is oppositely orientated for mode I (see insets). Note, that anti-parallel orientation is energetically favoured and, hence, occurs at a smaller frequency.

Conclusion

In summary, we have investigated a metamaterial structure consisting of arrays of 3-D micro coils fabricated by automated wire bonding. We use THz time-domain spectroscopy and complementary numerical simulations to characterize the response of the system. These novel structures offer considerable potential as a photonic 3D metamaterial at THz frequencies. In future studies we intend to investigate different aspects, such as magnetic excitation of the coils, the dependence of the response on the number of windings, particularly with regard to studying the crossover from antenna behavior to a L-C resonator, as well as the chiral aspects of our structures.

References

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