Terahertz Near-Field Imaging of Electric and Magnetic Resonances in Plasmonic High Frequency Devices

Andreas Bitzer[1,2]*, Jan Wallauer[1], Hannes Merbold[2], Florian Enderlin[2], Thomas Feurer[2], Hanspeter Helm[1], and Markus Walther[1]

[1] Freiburg Materials Research Center, University of Freiburg, Stefan-Meier-Strasse 21, D-79104 Freiburg, Germany

[2] Institute of Applied Physics, University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland

*Corresponding author: bitzer@iap.unibe.ch

Abstract: we report a terahertz near-field imaging approach which provides spatially resolved measurements of the amplitude, phase, and polarization of the electric field. Using this approach we extract the microscopic near-field signatures in plasmonic devices and planar metamaterials.

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Artificial media constructed from sub-wavelength plasmonic resonator structures or structured metallic surfaces exhibit remarkable electromagnetic properties and thus have attracted great interest in recent years [1, 2, 3]. In spite of the simple geometry of the resonant building blocks such metamaterial structures typically exhibit a rather complicated response to an incident electromagnetic wave and can be considered as a ultrafast plasmonic circuit.

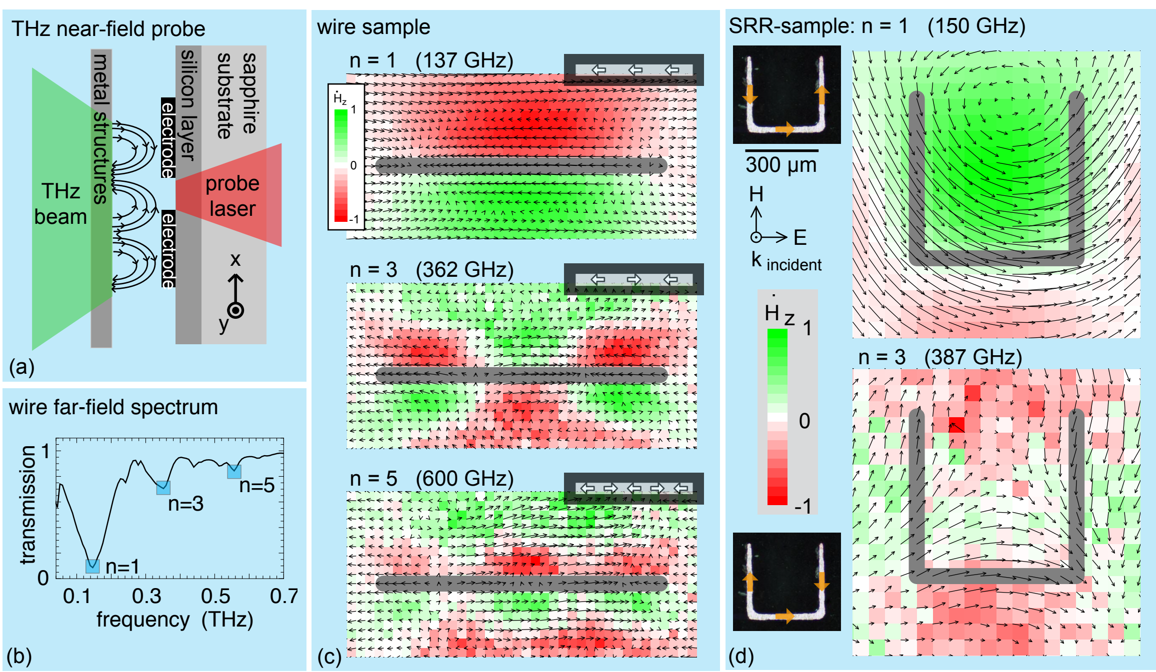

Fig. 1: a) Cross section of the detector chip close to the sample configured for a near-field measurement of the x-component of the electric field. b) Far-field spectrum of a rectangular array of micro wires obtained with conventional THz time-domain spectroscopy. The fundamental resonances and transmission minima that originate from the excitation of plasmonic eigenmodes along the wires are indicated (n=1, n=3, n=5). c) THz near-field scan of a single micro wire at its plasmonic resonances (n=1, n=3, n=5) corresponding to a). The in-plane electric and out-of-plane magnetic near-fields are indicated by the arrows and color code respectively. d) THz near-field scan of a single split-ring resonator at its plasmonic resonances (n=1, n=3) .

Due to the lack of suitable experimental techniques, simulation established itself as the standard tool to characterize the resonant microscopic behavior of such media. Here we report a terahertz near-field imaging method [4, 5, 6, 7] which provides insight into the underlaying mechanisms of various plasmonic devices ranging from metamaterial structures up to the characterization of photonics crystals, waveguide designs and many more.

Our technique is based on the THz time-domain approach. Terahertz pulses are emitted and detected by photoconductive antennas optically gated by the output of a mode-locked Ti:sapphire laser ($<$ 20 fs, 800 nm, 75 MHz repetition rate) [8, 9]. In contrast to conventional THz spectroscopy our detector unit features a near-field scanning probe consisting of a movable detector chip close to the sample surface as indicated in Fig. 1 a). This allows us to trace the electric field vectors close to the structures on sub-ps time scales with a sub-wavelength spatial resolution $< \lambda/25$. From the measured in-plane electric vector fields we are also able to reconstruct the out-of-plane magnetic field vectors. As a result we obtain a comprehensive microscopic picture of the electromagnetic near-field response of the sample as shown in Fig. 1 c) for a metallic micro-wire and a split-ring resonator structure d) which have been excited by broadband terahertz radiation. The near-field images are correlated with corresponding far-field spectra as shown in Fig. 1 b) for the wires.

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