THz pulse propagation along inkjet-printed metal stripes: Towards a 3D wire-medium for subwavelength imaging

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Abstract—An experimental investigation of transport mechanisms through a wire medium in the THz regime is performed. It captures a distribution of the electric field at the front interface and transmits it to the backside without distortion. In order to understand the canalization effect and basic transportation mechanism we measured near-field distribution caused by an incoming pulse at the backside with THz near-field spectroscopy and studied bandwidth, amplitude and polarization of the transmitted wave.

I. INTRODUCTION AND BACKGROUND

THE resolution of common imaging systems is restricted by the diffraction limit. The reason is that these systems cannot transport evanescent waves which carry subwavelength information. One promising way to overcome this limit is the use of wire media which first were proposed in [1] and demonstrated experimentally in [2]. Since distances between the wires are smaller than wavelengths of an incoming pulse the wire medium represents a metamaterial. The basic principle of operation of such endoscopes is based on the idea to transform the whole spectrum of spatial harmonics, including evanescent waves, into propagating eigenmodes of an array of metallic wires [3], [4]. This regime of operation is known as canalization and enables the propagation of the subwavelength fine details across a planar metamaterial slab, provided the thickness of the slab is tuned to obey the Fabry-Pérot resonance condition [5]. Using THz near-field microscopy, we investigate field canalization through a wire medium at THz frequencies. For this purpose we first study field propagation along individual and stacked metallic striplines and then extend our study to their 3D arrangements.

II. DESIGN AND EXPERIMENT

The wire medium we used consists of 60 µm wide coplanar silver stripes inkjet-printed on polyimide foils (Kapton) (Fig. 1(a), 1(b) & 1(c)) [6]. Individual foils can be further stacked forming a 3-dimensional wire medium. In order to study the basic transportation mechanism through such a medium 1, 2 and 40 copper stripes were printed on polyimide substrates. Using THz near-field microscopy we map the electric field distribution along the area of the samples and at the output of the medium in x-, y- and z-direction [7].

A single wire, two horizontally or vertically arranged parallel lines as well as an array of 2 x 2 parallel wires form unit cells of the wire medium. Understanding the wave propagation in these basic structures is of importance for it offers more insight into the behavior of more complex wire media. For reasons of simplicity a single split ring resonator (SRR) with a resonance frequency at 162 GHz was used as dipole source by exciting the SRR with a THz pulse (see Fig. 2(a)). The SRR was placed at the upper edge of the sample between two lines. A metal plate with a hole placed above the SRR and the sample acts as a shielding. The polarization of the wave coupled in the wires can be changed by turning the orientation of the sample with respect to the SRR. Hence, it is possible to produce quasi-TEM and TE modes propagating along the stripes. In the case of excitation by a field which is perpendicular to the strips, the sample and the SRR were twisted a bit in order to prevent interference with the electrodes of the antenna.

A wire medium was formed by stacking the sample foils upon each other. Sample and spacer layers are stretched with the aid of four needles, which are passed through lasered alignment holes. We placed a aperture in the pulse focus in front of the source plane and scanned the field distribution on the image plane. Further measurements without aperture or wire medium were carried out for comparison.
III. RESULTS

At first the propagation of the pulse coupled in the wires along the sample surface was measured. The orientation of the sample with respect to the polarization of the incoming pulse and SRR determined the propagating mode along the wires. In Fig. 2(b) and 2(c) the x-component of the electric field distribution at 0.16 THz and 0.48 THz is shown for a double line sample respectively. The SRR is located in the upper right edge of the picture. The wave front of the quasi TEM-mode is straightened and confined along the two wires. The same effect can be seen in Fig. 2(e). Here, the sample is a wire grid consisting of 30 striplines. The wave front is not only straightened but also the maximum of the field is confined exactly along the two stripes where the SRR is located. Thus, the x-position of the SRR can be determined with subwavelength resolution on the other end of the sample. If the wire grid is rotated by 90° TM-modes are excited. The field distribution at 0.16 THz can be seen in Fig. 2(g). The SRR is located in the middle of the right hand side. The wedge-shaped field distribution is striking. It might be due to an interaction with the antenna of the detector, since part of the pulse is guided along the antenna electrodes.

In a further step the wire medium was built. In order to investigate if it is possible to transport a near-field image through the wire medium, a double hole aperture was placed in front of it (Fig. 3(a)). The result of the measurement at the other end of the wire medium at 0.14 THz is shown in Fig. 3(b). The original position of the two holes is indicated by the drawn circles. The field distribution can be evaluated as an indication that it is possible to transport the near-field information on the position of the holes through the wire medium.

IV. CONCLUSION

In summary, we investigate the field distribution at the output of wire media in the THz regime consisting of single, double and multiple lines arranged coplanarly and in arrays. These investigations are directed towards the application of wire media for sub-wavelength imaging at THz frequencies.

REFERENCES