Wire medium made of inkjet-printed polyimide foils forming a subwavelength imaging device

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Summary: A wire medium is a device which is capable to transmit an electric field distribution with subwavelength resolution. Thereby, transfer of an image occurs in principal without spatial distortion and over an arbitrary long distance. We investigate the transport mechanism through a wire medium in the THz regime. In order to understand the transport and the underlying canalization effect we measured the transmitted field distribution caused by an incoming pulse at the backside with THz near-field spectroscopy and compared the results with simulations.

1 Introduction and Background

The wire medium is a type of complex artificial material consisting of parallel, thin wires with subwavelength distance embedded within a host medium [1], [2]. Therefore, it represents a hyperbolic metamaterial that combines dielectric and metallic properties. Thus it can be understood as an anisotropic crystal, i.e. electrical response (dielectric tensor $\hat{\varepsilon}$) is depending on the direction of the incoming wave. The expression, hyperbolic metamaterial, derives from the fact that the wave vectors span a hyperboloid in k-space. This leads to unusual properties which allow diffraction free imaging and focusing.

In common imaging systems the resolution is restricted by the diffraction limit. These systems cannot transport evanescent waves which carry subwavelength information. In contrast, the basic principle of a wire medium's imaging capability is based on the idea to transform the entire spectrum of spatial harmonics, including evanescent waves, into propagating eigenmodes of an array of metallic rods [3], [4], [5]. This regime of operation is known as canalization and enables the propagation of subwavelength fine details across a planar metamaterial slab. Using THz near-field microscopy, we investigate field canalization through a wire medium at THz frequencies.

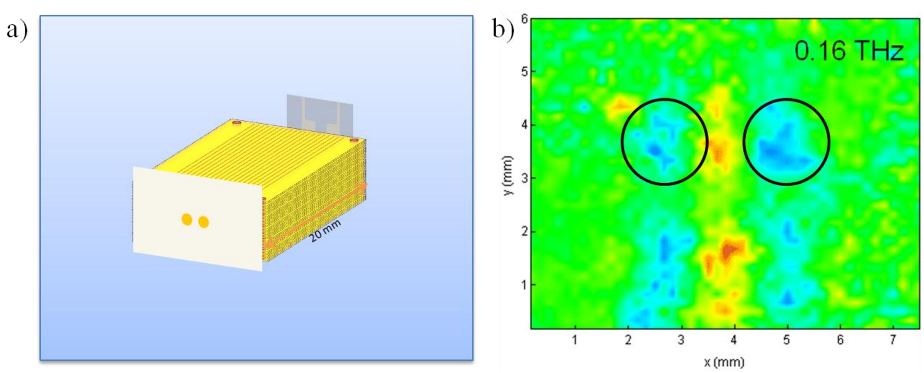

Figure 1: a) sketch of the bulk wire medium with a double aperture placed at the source plane and the detector on the image plane, b) measured x-component of the electric field on the image plane; color code corresponds to the normalized x-component of the electric field: blue = -1, green = 0, red = +1

2 Experiment and Results

We have fabricated different wire medium samples by inkjet-printing 60 µm wide coplanar silver stripes onto polyimide (Kapton) foils [6]. The individual foils can be further stacked separated by polyimide spacers forming a 3-dimensional, bulk wire medium (Fig. 1a). Using THz near-field microscopy we are able to map the transmitted field at the output of the bulk medium [7]. In order to demonstrate image transport through the wire medium a double aperture (a metal screen containing two holes) has been placed in the THz focus, directly in front of the source plane. The transmitted field distribution was mapped on the image plane. Further measurements without metal screen or wire medium were carried out in order to compare them. The results indicate transport of near-field of two illuminated holes through a 20 mm long wire medium with low spatial distortion (Fig. 1b). For a better understanding, electromagnetic simulations are performed with a commercial full-wave time domain solver, CST Microwave Studio, based on the finite-element method. As an example Fig. 2 shows the confined, propagating pulse in the wire medium.

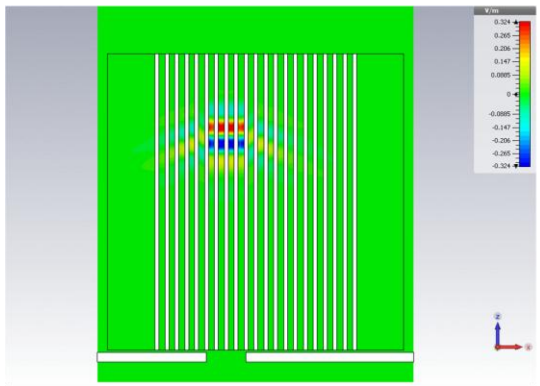

Figure 2: confined, propagating pulse in the wire medium.

3 Conclusion

In summary, we investigate the field distribution at the output of wire media in the THz regime. These investigations are directed towards the application of wire media for subwavelength imaging at THz frequencies.

References

[1] P. A. Belov, C. R. Simovski and P. Ikonen, "Canalization of subwavelength images by electromagnetic crystals," *Phys. Rev. B*, no. 71, p. 193105, 2005.

[2] P. A. Belov, Y. Hao and S. Sudhakaran, "Subwavelength microwave imaging using an array of parallel conducting wires as a lense," *Phys. Rev. B*, vol. 73, p. 033108, 2006.

[3] M. G. Silveirinha, P. A. Belov and C. R. Simovski, "Subwavelength imaging at infrared frequencies using an array of metallic nanorods," *Phys. Rev. B*, vol. 75, no. 3, p. 035108, 2007.

[4] M. G. Silveirinha, "Nonlocal homogenization model for a periodic array of ε-negative rods," *Phys. Rev. E*, vol. 73, no. 4, p. 046612, 2006.

[5] A. Rahman, P. A. Belov, Y. Hao and C. Parini, "Periscope like endoscope for transmission of a near field in the infrared range," *Opt. Lett.*, vol. 73, no. 2, pp. 142-144, 2010.

[6] M. Walther, A. Ortner, H. Meier, U. Löffelmann, P. J. Smith and J. G. Korvink, "Terahertz meetamaterials fabricated by inkjet printing," *Applied Physics Letters*, vol. 95, no. 25, p. 251107, 2009.

[7] A. Bitzer, A. Ortner and M. Walther, "Terahertz near-field microscopy with subwavelength spatial resolution based on photoconductive antennas," *Appl. Opt.*, vol. 49, no. 19, pp. E1-E6, 2010.