Perfect image transport by a wire array metamaterial fiber

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Abstract— **One promising approach to overcome the diffraction limit in image propagation is based on using a metamaterial hyperlens composed of an array of subwavelength scaled metal wires. Here we will present new results on transmission of terahertz (THz) near-field distributions of different resonant and plasmonic structures providing a distinct longitudinal polarized field pattern through a wire array metamaterial fibre imaged by terahertz near-field microscopy.**

I. INTRODUCTION

THE resolution of common imaging systems is restricted to approximately half the wavelength as a result of the diffraction limit and the exponentially decaying nature of evanescent waves with high spatial frequencies that carry the information on the subwavelength details of an object. A promising approach to overcome this restriction is the metamaterial hyperlens composed of an array of subwavelength scaled metal wires [1]. Such a structure is also known as "wire medium". It is characterized by extreme optical anisotropy and spatial dispersion which leads to flat isofrequency contours and transverse electromagnetic (TEM) extraordinary eigenmodes that support high spatial harmonics. Thus, wire media provide an opportunity to transmit the near-field with super-resolution. At the source plane transverse magnetic (TM) polarized evanescent waves can be transformed into propagating TEM waves, preserving subwavelength information. These TEM waves propagate along the wires through the wire medium and reproduce the field distribution at the image plane. This phenomenon is called canalization. By using electric fields that are polarized orthogonal towards the front interface of the wire medium, perfect imaging can be achieved since the electromagnetic waves are constituted exclusively by extraordinary waves, filtering out all ordinary waves. We have previously demonstrated sub-diffraction limited imaging of subwavelength scaled apertures with a wire metamaterial fibre achieving a resolution of λ/27 by mapping transverse polarized fields [2]. Here we experimentally demonstrate the transmission of spatial field distributions through a wire metamaterial fibre which are polarized orthogonal with respect to the front interface as generated for instance by a complementary split ring resonator.

II. EXPERIMENTAL DETAILS

The wire metamaterial fibres are fabricated by a fibre draw technique [3, 4]. The fibres contain 453 hexagonally arranged indium wires of nominally 10 µm diameter and 50 µm pitch. As illustrated in Fig. 1 we used two fibres of 1.36 mm and 6.76 mm length.

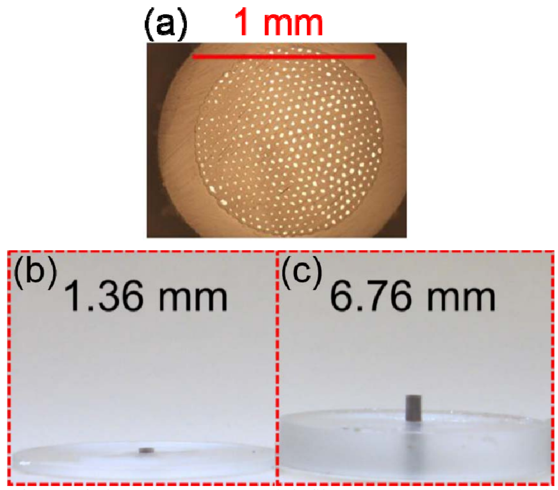

Fig. 1. Photo of the wire metamaterial fibres; (a) top view showing the interface, (b) 1.36 mm long fibre and (c) 6.76 mm long fibre with mount.

As one example, we show that it is possible to transport the field distribution of a complementary split ring resonator (CSRR) through the metamaterial fibre [2]. The fields are polarized orthogonally to the source plane of the hyperlens as required for a field transport without diffraction. The CSRR has a side length of 500 µm, a gap size of 150 µm and slit width of 10 µm (Fig. 2). Hence, it has two transmission maxima at 75 GHz and 225 GHz. In the near field one observes the characteristics of a dipole and quadrupole field pattern at 75 GHz and 225 GHz, respectively [3].

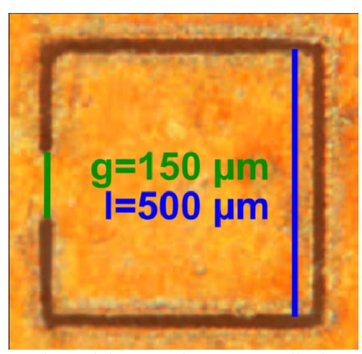

Fig. 1. Top view of the complementary split ring resonator.

A single CSRR is illuminated with linearly polarized THz pulses and the field distribution is mapped on the backside of the structure with and without the metamaterial fibres on top. For this purpose we measured the electric field distribution with a terahertz near-field microscope [4]. By using an electro-optical detection scheme with a ZnTe crystal cut in (100)-direction in order to measure the longitudinal field component, we directly map the field in close vicinity to the sample and are able to reconstruct the field pattern in the time and the frequency domain.

III. Results

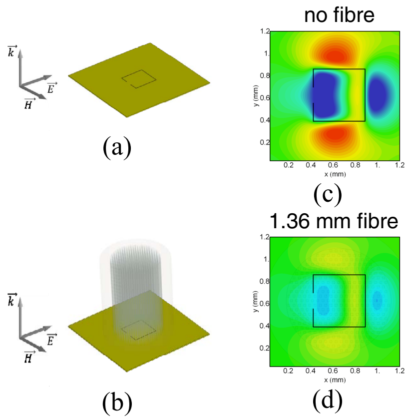

Fig. 2. Illustration of the CSRR (a) without fibre and (b) with fibre; simulated out-of-plane-component of the field distribution at 225 GHz (c) without fibre and (d) with a 1.36 mm long fibre. Colour code: red=-1, yellow=-0.5, green 0, cyan=+0.5, blue=+1.

In Figure 3 the out-of-plane-component of the electric field distribution obtained by simulation (c, d) is shown at the 3rd-order resonance of the CSRR at 225 GHz. Fig 3c shows the simulated field pattern of the CSRR due to the quadrupole mode. This field distribution is reconstructed at the image plane of the metamaterial fibre and maintains its characteristic pattern (Fig. 3d).

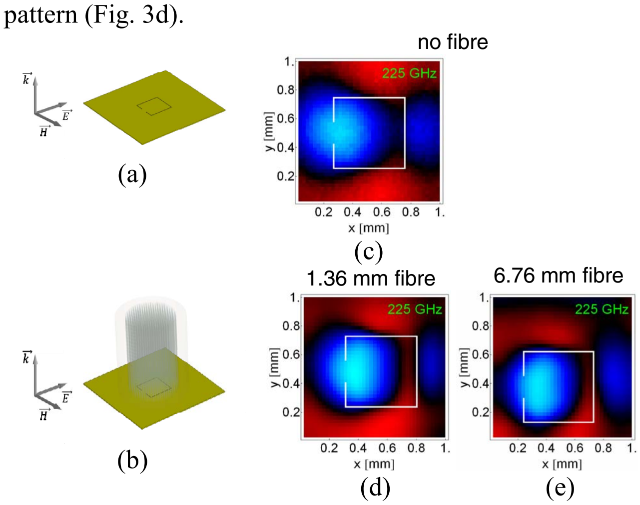

Fig. 4. Illustration of the CSRR (a) without fibre and (b) with fibre; measured out-of-plane-component of the field distribution at 225 GHz (c) without fibre ,(d) with the 1.36 mm long fibre and (e) with the 6.76 mm long fibre. Colour code: yellow=-1, red=-0.5, black=0, blue=+0.5, cyan=+1.

The measured field distribution of the CSRR is in good agreement with the simulation and also shows the quadrupole mode pattern (Fig. 4c). The same field pattern is also observed at the output of the fibre in contact with the illuminated CSRR (Fig. 4d,e), demonstrating that the metamaterial fibre is capable of transporting electromagnetic fields that are polarized along the propagation direction, at all frequencies.

IV. Summary

We demonstrate the image transmission capability of a metamaterial-hyperlens made of an array of metal wires. By mapping the longitudinal field component of a single excited CSRR after transmission through a wire medium we are able to prove the transport of complex field distributions over distances of several wavelengths. Our results demonstrate the diffraction-less transport of evanescent field distributions paving the way towards perfect imaging by wire-array fiber.

References

[1]. C. R. Simovski, P. A. Belov, A. V. Atrashchenko and Y. S. Kivshar, Advanced Materials, vol. 24, no. 31, pp. 4229-4248, 2012.

[2]. A. Tuniz, K. J. Kaltenecker, B. M. Fischer, M. Walther, S. C. Fleming, A. Argyros and B. T. Kuhlmey, Nature Communications, vol. 4, no. 2706, 2013.

[3]. A. Tuniz, B. T. Kuhlmey, R. Lwin, A. Wang, J. Anthony, R. Leonhardt, and S. C. Fleming, Appl. Physics Letters, vol. 96, no. 19, 2010

[4]. A. Tuniz, R. . Lwin, A. Argyros, S. C. Fleming, and B. T. Kuhlmey, J. Vis. Exp., vol. 68, no. e4299, 2012

[5]. A. Bitzer, A. Ortner, H. Merbold, T. Feurer and M. Walther,Optics Express, vol. 19, no. 3, pp. 2537-2545, 2011.

[4] A. Bitzer, A. Ortner and M. Walther,Appl. Opt., vol. 49, no. 19, pp. E1-E6, 2010.