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Split-ring resonators hyperlens for undistorted sub-wavelength imaging

Alessio Stefani^{1,2}, Juliano Grigoletto Hayashi², Simon Fleming², Alexander Argyros², Boris T. Kuhlme²

1. DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark

2. Institute of Photonics and Optical Sciences (IPOS), School of Physics, The University of Sydney, NSW, 2006, Australia

Hyperbolic metamaterials offer a unique solution to overcome the diffraction limit due to the ability of propagating high spatial frequencies [1]. To date, there have been several demonstrations of hyperbolic metamaterials that can convert evanescent fields into propagating waves based on their geometrical structure and therefore can be used as lenses [2-4]. The drawback of all the proposed hyperlenses is that the hyperbolic dispersion is given by the anisotropy of the permittivity only. This means that in such lenses only one of the propagating polarizations is non-diverging while the other (e.g., TE modes for a wire array) sees an “ordinary” material resulting in distorted images [4]. To overcome this limitation, a metamaterial which also has anisotropic permeability is necessary. Here, we propose a solution to this problem by realizing a hyperlens made of split-ring resonators (SRRs). In a first approximation, the SRRs behave as wires for transverse magnetic modes, and thus have anisotropic permittivity, and as magnetic resonators for transverse electric modes, and thus leading to anisotropic permeability. The resonators, made of tin in a Soda Lime glass matrix are fiber drawn, the target wavelength is 3 μm and magnification is achieved by tapering of the structure. Tapered, fiber drawn hyperlenses, based on wire arrays, have been reported in polymers for the THz spectral region [4] and in soft glass for the mid-IR [5]. Polymer fiber drawn SRRs and their behavior have been reported for THz frequencies [6,7].

Finite-element (COMSOL) simulations [8] are used to calculate the dispersion relations of an indefinite SRRs medium and results are shown in Fig. 1(a). Few modes are allowed in the structure, but no ordinary wave with spatial frequency cut off is present. One low loss mode (quasi TEM - black squares) shows the desired hyperbolic dispersion while the other modes have much larger loss and/or are evanescent, allowing for undistorted imaging. The array of SRRs, an example of which is shown in Fig. 1(b), is realized by stack and draw. To confirm that the fiber drawing scaling process does not compromise the properties of the resonators, THz frequency sized SRR arrays were tested for transmission across the array. Fig. 1(c) shows the THz time domain spectroscopy (TDS) measured and simulated transmission. The SRR’s magnetic resonance is clearly visible and, as expected and in accordance with the simulations, the resonant frequency shifts to higher frequencies as the resonators get smaller. Inset: microscope images of the SRRs (black, metal; light, glass).

Currently, SRRs on the order of 5 μm are realized. Further scaling of the structure by a factor ~ 5 and tapering will permit the hyperlens to be tested for imaging at 3 μm , while the current dimensions are suitable for THz imaging.

Fig. 1 (a) Calculated dispersion and field profiles (insets) of an indefinite array of 250 nm (outer size) SRRs, pitch=500 nm, at $\lambda=3 \mu\text{m}$. (b) Fiber drawn Soda Lime SRRs array before metal filling. (c) Simulated and measured transmission (THz TDS) through arrays of SRRs with various scaling. Inset: microscope images of the SRRs (black, metal; light, glass).

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