Fiber metamaterials for terahertz applications

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Abstract

We present recent progress in fiber-based metamaterials. We have drawn fibers containing either sub-wavelength magnetic resonators or wire media, operating up to mid-infrared frequencies. This has led to the first fiber-based metamaterial hyperlenses capable of imaging and focusing well below the diffraction limit over optically long distances, at terahertz frequencies.

Introduction

Metamaterials are a new class of artificial composite optical materials, fabricated by assembling components much smaller than the wavelength at which they operate, and possessing effective parameters that are not found in nature [1]. This unprecedented control over the behavior of light has led to the demonstration of devices with novel functionalities, e.g. lenses that resolve objects below the diffraction limit [2]. Recent fabrication capabilities provide great flexibility in terms of material choice and size [3], however metamaterials at frequencies higher than a several gigahertz are typically fabricated in planar geometries, where only small amounts of metamaterial are produced at a time. Furthermore, the processes used do not lend themselves to the fabrication of metamaterials in industrial quantities. In recent years, we have developed a method to bulk-produce hundreds of meters of metamaterials in fiber form, by adapting the drawing techniques used to produce optical fibers. With this method, metal wires or foils are arranged inside a cylindrical dielectric on the centimeter scale, then drawn to fibers containing a scaled-down version of the original structure.

Early experiments resulted in metamaterial fibers containing metal micro-wires [4-5] (possessing a tailored electric permittivity) and metal micro-resonators [6-8] (possessing a tailored magnetic permeability). Most recently, we have produced drawn structures containing wire media that can propagate and focus deeply sub-wavelength information at terahertz frequencies, over optically long distances [9]. Whereas the resolution of conventional lenses is bound by the diffraction limit to about half the wavelength of light, these structures beat this limit by an order of magnitude. Imaging at terahertz frequencies (wavelengths between 3 mm and 30 μm) is a powerful new tool with applications across a range of disciplines [10], e.g. bio-molecule detection [11], cancer diagnosis [12], system inspection [13], and illegal drug detection [14]. However, terahertz imaging is currently under-used, also due to the limited availability and functionality of optical tools in this region – particularly in terms of resolution. This fiber-based geometry can be made on an industrial scale, and thus promises to be a powerful new tool for medicine, biology, chemistry and physics.

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