Porous Fibers: Low loss, low dispersion waveguides for terahertz transmission

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Abstract— We demonstrate that porous fibers can offer both broadband low loss guidance and flattened group velocity, and thus that they are a promising new range of dielectric waveguide structures for the terahertz regime.

I. Introduction

WAVEGUIDE technologies for guiding THz radiation do not at present allow low loss and low dispersion transmission[1]. Sub-wavelength plastic fibers[2] (described as THz microwires[3] in analogy with optical nanowires) with attenuation constants less than 0.01 cm^{-1} have the lowest loss reported in the literature for dielectric waveguides. The low loss characteristic of microwires is associated with the fact that most of guided field propagates outside the microwire, resulting in poor field confinement. Thus, as a, the guided modes within these structures suffer strong bend loss[4].

Recently, a novel class of porous fibers for the THz range was suggested independently by two research groups[1,5]. Porous fibers are air-clad fibers that contain a pattern of sub-wavelength air-holes in the core. Such fibers allow low loss THz propagation and a better confinement of the field relative to microwires[1]. Porous fibers have a comparable attenuation to microwires but offer an improved confinement of the mode to the structure[1].

Here, we demonstrate that porous fibers, in addition to their higher confinement[1], have lower dispersion and flatter frequency dependence of the loss in comparison with those of microwires. This makes this class of fiber an ideal waveguide for low loss and low distortion THz transmission.

II. Porous Fibers

Porous fibers are created by introducing sub-wavelength low-index discontinuities within the core of air-clad fibers; see the example in Fig. 1(a). For these fibers, the porosity is defined as the fraction of the air holes to the core area. Fig. 1(b) shows the normalized *z*-component of the Poynting vector (S_z) of the fundamental mode of the porous fiber along the cross-section shown in Fig. 1(a). The refractive index profile along the same axis is also shown, demonstrating where the sub-wavelength air-holes are located. The refractive indices n_1 and n_0 refer to material (PMMA) and air refractive indices, respectively. As Shown in Fig. 1(b), the field is enhanced at the each air-material interface and remains localized in the sub-wavelength air-holes, where the refractive index is n_0. This phenomenon occurs for all the sub-wavelength air-holes in the structure, resulting to a better field confinement to the porous fiber compared to microwire[1].

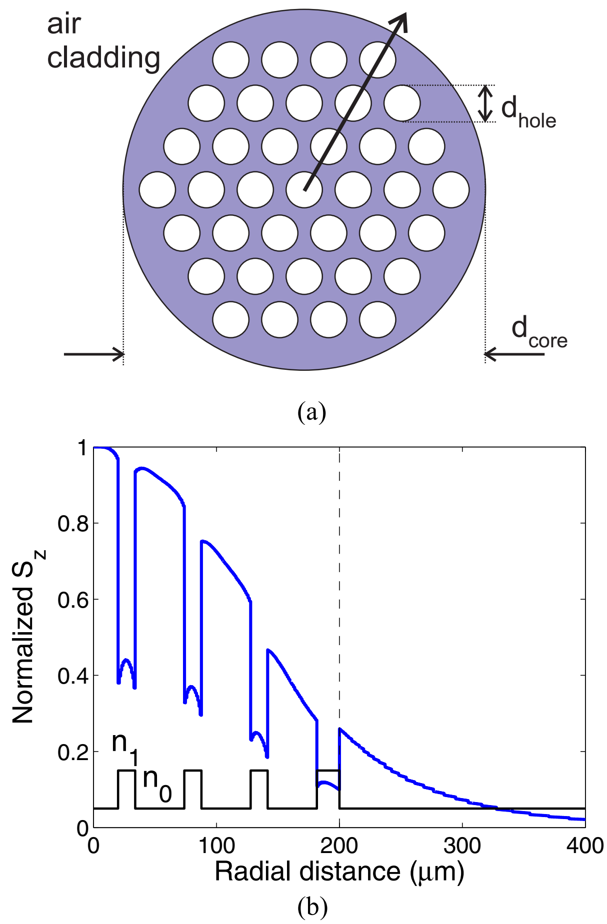

Fig. 1 (a) Cross-section and geometrical definitions of the triangular lattice porous fiber. (b) The normalized *z*-component of the Poynting vector (*S*z) along the cross-section shown in fig. 1(a). After [1].

III. Results: Loss And Dispersion

Fig. 2 shows the effective material loss, α_{eff}, versus frequency of a porous fiber with 74% porosity and a microwire. The diameters of the fibers (500 µm and 250 µm respectively) are chosen in a way that they both have identical loss[1] at 0.2 THz. As shown in Fig. 2, the loss increases with increasing frequency due to the fact that the power fraction within the core increases. For porous fibers; however, since most of the field in the core is localized in the sub-wavelength air-holes, which are transparent for THz transmission, the increase in α_{eff} is less pronounced than in the microwire. For frequencies larger than 0.4 THz the effective material loss of the porous fiber is three orders of magnitude lower than that of the microwire.

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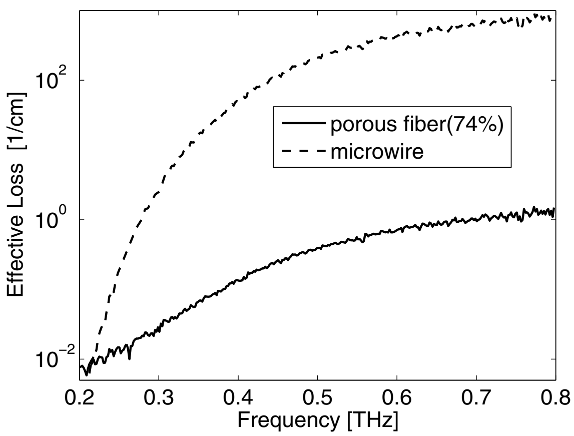

Fig. 2 Effective material loss, after [1] a porous fiber with 74% porosity and a microwire versus frequency.

Dispersion is another mechanism that leads to signal degradation in broadband applications. This occurs when the propagation constant of the guided modes varies with frequency, i.e. due to refractive index variation of the material and/or waveguide structure. To calculate the waveguide dispersion of the fibers, the group velocity $\nu_g = \partial\omega/\partial\beta_{eff}$ is calculated. Figure 3 shows the group velocity normalized relative to the speed of light in free space as a function of frequency. For lower frequencies, the group velocity of the propagating mode in both structures approaches the velocity of light in free space. By increasing the frequency, the group velocity drops to that of the bulk host material. Since less material resides in the core of porous fiber, the drop is lower relative to that of the microwire and plastic ribbon THz waveguide[6] ($\nu_g/c \sim 0.68$ at 0.8 THz). Thus a terahertz pulse propagating along the porous fiber encounters relatively lower normal dispersion, corresponding to positive chirp in the time domain for 0.2-0.8 THz, Fig. 3. Thus porous fibers offer reduced distortion of the THz spectrum compared to THz microwires; three orders of magnitude less loss and flattened group velocity ($\nu_g/c \sim 0.88$ at 0.8 THz).

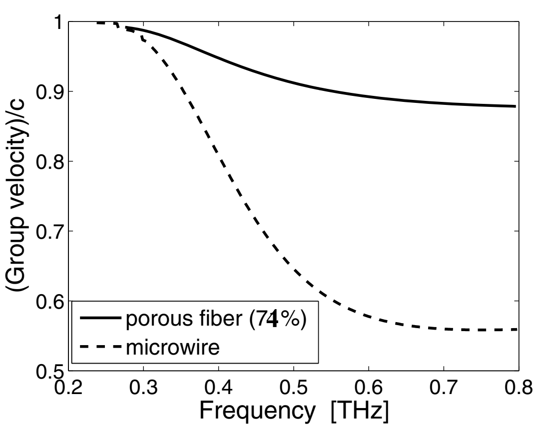

Fig. 3 Group velocity normalized to the speed of light in free space of a porous fiber with 74% porosity and a microwire versus frequency.

The full details of the loss and dispersion calculations versus frequency for different diameters of both fiber structures and different porosity values will be presented and discussed.

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