Broadband Porous-Core Bandgap Terahertz Fiber Based on Kagome Lattice of Air Holes

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Abstract—**We propose a novel bandgap fiber for the transmission of terahertz (THz) radiation based on a Kagome lattice of air holes. The fiber core comprises a triangular lattice of air holes having the same or a smaller size than the cladding air holes. Numerical simulation of a 19-cell fiber is carried out using finite element method. Proper design of the fiber parameters allows the transmission of broadband THz radiation in the 1.0~2.3 THz range.**

I. INTRODUCTION

With the rapid advances in the generation, detection, and applications of terahertz (THz) radiation [1,2], there is also increasing interest in THz waveguides [3]. The use of waveguide-based in replacement of free-space transmission of THz radiation will lead to more compact THz systems and improved functionalities. The current problem is that the high metallic loss or the absorption loss significantly hinders the development of low-loss and long-length waveguides for the THz range [3].

For dielectric THz waveguides, the design strategy is therefore to maximize the THz field in dry air, which has a lower loss than the materials used, in order to lower the propagation loss. To this end, several types of hollow-core THz fibers have been proposed [3], such as fibers based on the photonic bandgap (PBG) effect [4,5], tube-lattice fibers based on the inhibited coupling mechanism [6,7], and Kagome fibers [8] based on a low overlap of the core mode and the cladding modes. Another approach is to use a number of subwavelength air holes in the fiber core so that a large fraction of mode power resides in air. Such fibers are known as porous-core fibers [9,10]. Recently, a new type of PBG THz fiber, which consists of a honeycomb cladding of air holes with a porous core, has been reported [11].

Here, we report the design of a porous-core Kagome bandgap fiber that allows the transmission of broadband THz radiation in the 1.0~2.3 THz range.

II. SIMULATION RESULTS

The fiber is based on the photonic bandgap effect [12] resulting from a Kagome lattice of air holes, as shown in Fig. 1. It should be emphasized that this fiber is different from the commonly used terminology in the optics community, where Kagome fibers refer to the structure formed by a pattern of tessellated ‘stars of David’ [8].

The Kagome lattice of air holes produces broad bandgaps but it is difficult to work under the air line, as with honeycomb fibers [11]. Therefore, the fiber core utilizes a porous-core design, i.e., a triangular lattice of air holes, to make sure that the effective core index falls below that of the Kagome cladding. The fiber parameters are similar to those in [12]: $d = 165$ μm, $\Lambda = 360$ μm, and D=3.65 mm. In addition, the index of the fiber material is assumed to be 1.5235 for all frequencies.

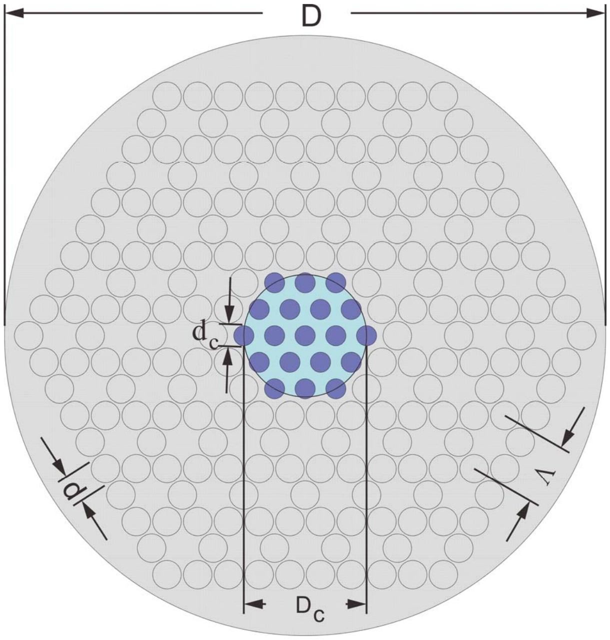


Fig. 1. Schematic of the fiber under study. The cladding is composed of a Kagome lattice of air holes of four layers. The porous-core comprises 19 air holes arranged in a triangular lattice.

Figure 2 shows the bandgaps of the designed structure and the effective mode indices of the fundamental HE_{11} mode. The PBGs are computed numerically using the MIT Photonic-Bands package (MPB).The calculated two bandgaps are shown in gray. The effective mode indices are obtained using commercial finite element method-based software COMSOL Multiphysics. Only one HE_{11} mode is shown in Fig. 2 due to the degeneracy of the HE_{11} mode pair.

Calculations yield two broad bandgaps, but if the core air holes have the same size as those in the cladding, i.e., d_c=165 μm, the wave is guided only in the second bandgap within the range of 1.33–1.74 THz (blue dashed curve). However, if d_c is reduced to 130 μm, the transmission range is 0.97–2.27 THz and falls within the lower bandgap (red solid curve). Hence, a broader transmission range is realized by reducing the diameter of the air holes in the porous core of our PBG fiber. A similar strategy has been used by Liang *et al* [13] to porous-core triangular lattice-based bandgap fiber. There, the air fraction in the core has to be larger than that of the cladding to ensure bandgap guidance. In our case, the air holes in the core can be smaller than the cladding air holes because it is easy for the triangular lattice of air holes to have a larger air fraction than the Kagome cladding.

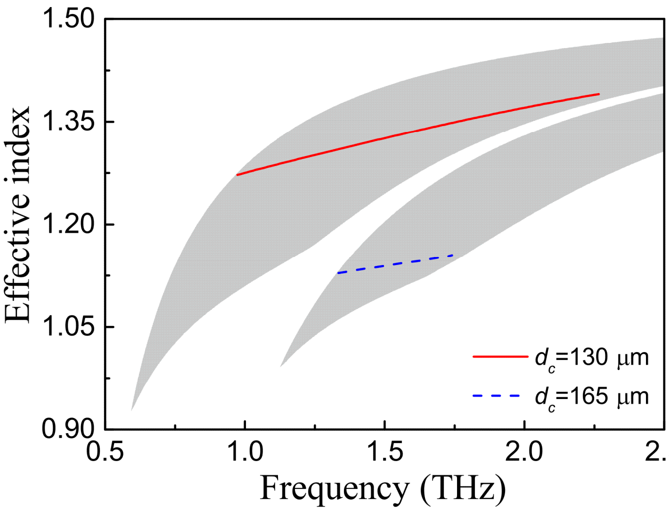
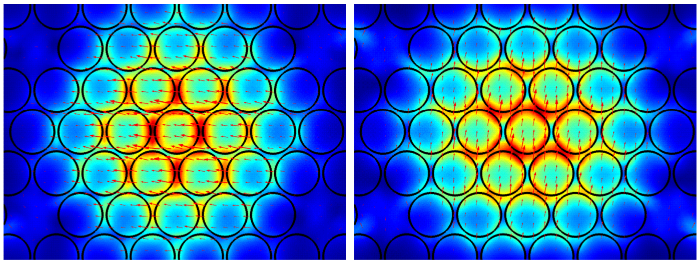


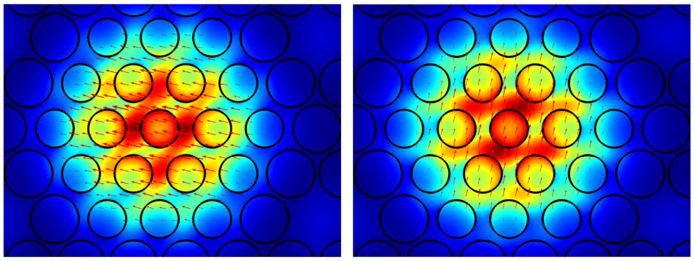
Fig. 2. Effective indices of the fundamental mode for different diameters of the air holes in the core.

The magnitude of the electric field and the transverse electric field pattern of the degenerate fundamental modes at 1.5 THz are shown in Figs. 3 and 4 for d_c=165 μm and d_c=130 μm, respectively. In both cases, the modes are well localized in the core region. But as can be observed, the electric field will try to avoid the air holes and be concentrated in the material region [12]. This is because here we use lattice-matched core designs to avoid any surface-like modes [14]. But other designs should also be possible. Closer examination of the two figures shows that more mode power will be in the dielectric region for the case of smaller core air holes. This suggests that the improved design has a larger bandwidth but at the cost of a slightly higher loss. Another issue is that here we have used a 19-cell unit in the core and previous studies have shown that such a large core tends to support more higher-order modes [15]. A 7-unit cell will be considered to reduce the number of higher-order modes. A detailed study of the fiber loss and a design strategy will be performed and presented elsewhere.



HE_{11}^{1} HE_{11}^{2}

Fig. 3. The magnitude of the electric field and the transverse electric field patterns of the degenerate fundamental modes at 1.5 THz within the second bandgap when d_c=165 μm.



HE_{11}^{1} HE_{11}^{2}

Fig. 4. The magnitude of the electric field and the transverse electric field patterns of the degenerate fundamental modes at 1.5 THz within the first bandgap when d_c=130 μm.

III. SUMMARY

In conclusion, we have characterized a new PBG THz fiber based on a Kagome lattice of air holes with numerical simulations. It is demonstrated that appropriate design of the air holes in the porous core can shift the working bandgap and allow the transmission of broadband THz radiation in the 1.0~ 2.3 THz range.

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