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Design and measurement of all-rod terahertz photonic crystal fiber with air-core

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ABSTRACT

An all-rod terahertz wave air-core photonic crystal fiber is designed and fabricated. Transmission spectra through the sample are measured by using terahertz time-domain spectroscopy system. Periodic transmission band and low loss of the fiber are experimentally proved. Measurement results show that the power loss of the present terahertz wave photonic crystal fiber is less than 1.9 dB/cm in transmission bands. The wave confinement ability of the fiber is also demonstrated.

1. Introduction

In past few years, terahertz applications mainly depended on free space systems. With the development of terahertz solid-state systems, waveguide devices are expected to play an important role. Among them, low-loss terahertz waveguides are of great importance for the practical terahertz application. Recently, several terahertz photonic crystal fibers have been reported, such as air-core microstructure fiber [1], air-core polymer microstructure fiber [2], band-gap based low loss air-core polymer fiber [3], cyclic olefin copolymer fiber [4], an elliptical arrangement of circular birefringence dielectric tubes fiber [5], single-mode single-polarization rectangular array photonic crystal fiber [6], and photonic crystal slab waveguide [7], and so on. Similar optical fiber structures with a low index core surrounded by a microstructure of discrete high index regions have been reported suggesting the guiding mechanism of the antiresonant reflecting optical waveguiding [8–10]. Simply, an array of high-index rods in a low-index background, the gaps between the transmission bands of the cladding give rise to the antiresonance of each individual high-index rod [11,12]. Those research results indicate that the polymer fiber has risen up to be one of the most important candidates of terahertz waveguides.

In this work, an all-rod terahertz bandgap photonic crystal fiber is proposed and fabricated. Instead of commonly used air holes, solid polymer rods are arranged to compose the photonic crystal fiber cladding. The defect core of the photonic crystal fiber is induced by removing the central rod. We experimentally measured and theoretically calculated results demonstrated that the proposed terahertz photonic crystal fiber has relatively low transmission loss (low to 1.9 dB/cm) and other advantages such as simple structure, the ease of fabrication and rigidness property.

2. Structure design and fabrication

Fig. 1(a) shows the designed all-rod air-core photonic crystal fiber. Its cladding is composed of Polytetrafluoroethene rods with the diameter $d=1$ mm. These rods are arranged to form a triangular lattice photonic crystal structure with a lattice constant $\Lambda=2$ mm. The defect core is introduced by removing the central rod, thus the core and the background are full of air. Fig. 1(b) depicts the photograph of the manufactured air-core photonic crystal fiber sample. To form the triangular lattice with lattice constant of 2 mm, 60 rods with the length $L=30$ mm are fixed by being inserted into 2 circular Polytetrafluoroethene slabs at both input port and output port.

In order to give a more credible comparison between the simulated and experimental results, a 2.45 mm thick Polytetrafluoroethene disk was characterized via a standard terahertz time-domain spectroscopy system charged with nitrogen gas. The refractive index and the absorption coefficient of the Polytetrafluoroethene are extracted from the measured complex transmittance spectrum through the slab, as shown in Fig. 2. The fluctuation on the curves at low frequency region attributes to that the THz wave intensity is very weak, thus the processed data is inaccurate at low frequencies. As expected, the absorption coefficient rises following the frequency increase.

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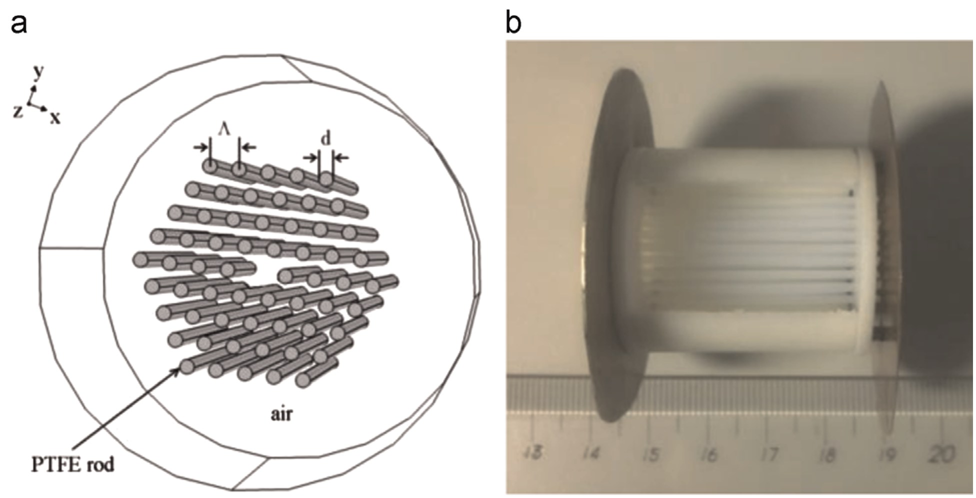

Fig. 1. (a) Structure of the proposed air-core photonic crystal fiber (b) photograph of the manufactured specimen.

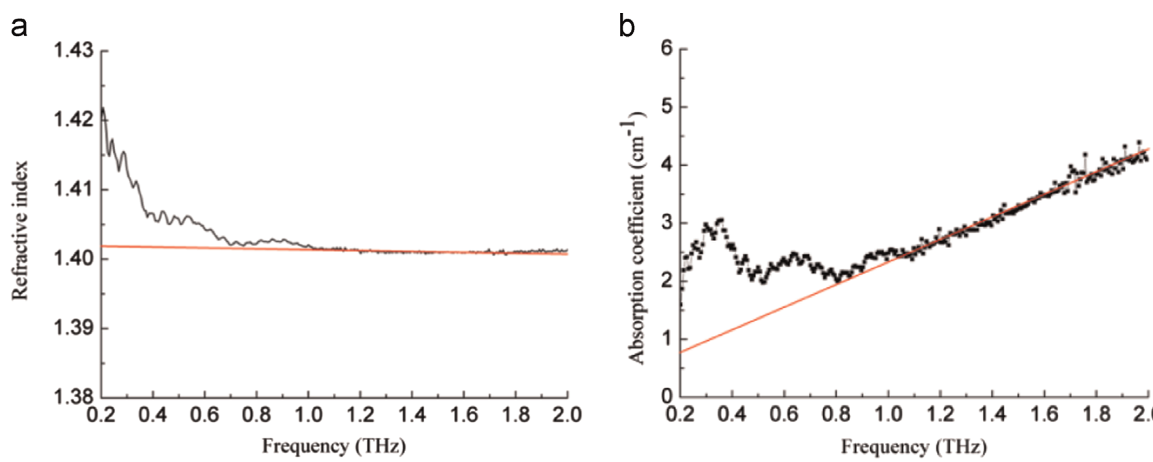

Fig. 2. (a)The refractive index (b) absorption coefficient of Polytetrafluoroethene (red lines are base lines presenting the trend). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The transmission spectra of the manufactured photonic crystal fiber are measured by a modified parallel-beam terahertz time-domain spectroscopy system, which is illustrated in Fig. 3. Two metal slices with a 3 mm-diameter hole is inserted at the input and output ports of the photonic crystal fiber to make the incident terahertz wave beam mainly cover the core (called aperture A and aperture B, respectively). Reference signal is measured by removing the photonic crystal fiber sample but remaining the holes. To eliminate the influences brought by water vapor, terahertz time-domain spectroscopy system is charged with nitrogen gas.

3. Calculation and experiment

Through calculating the effective mode index and the leakage loss of the guided mode in ideal waveguide structure, the wave guiding bands and gaps of the photonic crystal fiber can be clearly presented. The total propagating loss of the waveguide includes the mode leakage loss and the material absorption loss. It can be extracted from the imaginary part of the propagation constant. The mode propagating loss of photonic crystal fiber is defined as [13]

$$\text{Propagating loss} = 10 \times \log e^{2j(-Im[\beta]j)} \quad (1)$$

$$\text{Im}\,[\beta] = -\frac{2\pi f}{c}\,\text{Im}[n_{eff}],\ \ \text{Im}\,[\beta] = -\frac{2\pi}{\lambda}\,\text{Im}[n_{eff}] \quad (2)$$

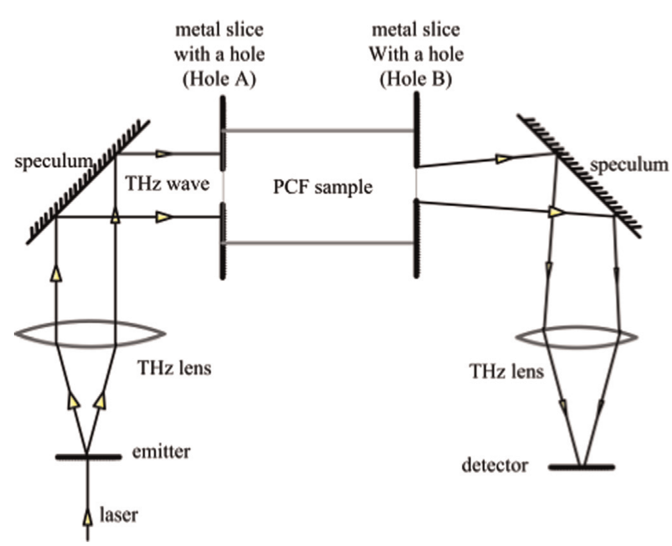

Fig. 3. Experimental setup in terahertz wave path.

where Im[β] and Im[n_{eff}] are the imaginary parts of the propagation constant and the effective index, respectively. Electric field transmittance is defined as