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Polarization-maintaining terahertz bandgap fiber with a quasi-elliptical hollow-core

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ABSTRACT

We present a polarization-maintaining photonic bandgap fiber (PBGF) in terahertz (THz) regime, consisting of a quasi-elliptical hollow-core (QEHC) and triangularly arranged hexagonal holes in cladding. Thanks to the specially designed core shape, the QEHC-PBGF can support two stable polarization-maintaining fundamental modes. From numerical simulations, birefringence, confinement loss and group velocity dispersion of the fundamental mode group are 9.4×10^{-4}, 3×10^{-3} cm^{-1} and 0.39 psTHz^{-1} cm^{-1} at 0.9 THz, respectively. Moreover, we investigate the fiber fabrication tolerance in the context of polarization-maintaining and confinement performances. The proposed QEHC-PBGF is anticipated to be useful in polarization sensitive THz applications.

1. Introduction

Covering wavelength generally defined from 30 μm to 3 mm (in frequency 0.1–10 THz), terahertz (THz) radiation has attracted increasing research attention [1]. Benefiting from the significant progresses of efficient THz sources and detectors [2,3], THz waves have been widely applied for sensing [4], imaging [5] and spectroscopy [6]. Currently, most of the THz systems are bulky since they rely on free-space transmission, thus flexible, compact and low-loss waveguides for broadband THz wave manipulation remain in urgent need. Since dry air is the most commonly used transparent THz medium, one solution to minimize the transmission loss is confining the major fraction of THz power in an air-core. Numerous hollow-core THz waveguides have been numerically proposed and experimentally demonstrated, including metamaterial waveguide [7], all-dielectric waveguide [8], dielectric-coated metallic waveguide [9], anti-resonant reflecting optical waveguide [10] and photonic bandgap waveguide [11]. At optical communication wavelength, hollow-core photonic bandgap fiber (HC-PBGF) has provided immense opportunities in significantly reducing the nonlinearity [12] and potentially achieving lower propagation loss [13,14] compared with conventional solid core fiber. We believe these intriguing properties of HC-PBGF would be advantageous for not only conventional communication wavelength but also the THz radiation. Generally, the guiding mechanism of PBGF is the formation of photonic bandgap, where the guided core modes are well confined. The bandgap characteristics are dictated by the periodic feature in fiber cladding, which can be flexibly arranged. Meanwhile, low group velocity dispersion (GVD) is also required for THz waveguides when short pulses propagate along the waveguide. GVD can be controlled by appropriate waveguide parameters [15] and a waveguide dispersion of several psTHz^{-1} cm^{-1} in a THz HC-PBGF has been reported [16].

Besides the loss and GVD properties, another issue of utmost importance is birefringence in the context of polarization sensitive THz applications, particularly the short-range THz communications [17,18]. In most polarization-maintaining fibers, birefringence is achieved by deliberately introducing anisotropy in the geometry [19]. Of date, the designs of polarization-maintaining THz waveguide mainly focus on the index-guiding photonic crystal fiber [20] and the dielectric-coated metallic elliptical core fiber [21]. Another candidate to achieve high birefringence is the HC-PBGF with asymmetric core shape. In 2009, Ren proposed a polarization-maintaining THz HC-PBGF with periodically arranged square holes in fiber cladding [22]. Nevertheless, less effort in designing THz birefringent HC-PBGF with triangularly arranged cladding has been reported. Additionally, the flexible fabrication processes of THz photonic crystal fiber make HC-PBGF a promising candidate in THz polarization-maintaining applications [23,24].

In this paper, we raise a proposal of highly birefringent THz fiber based on the guiding mechanism of photonic bandgap. The fiber design combines a 4-cell quasi-elliptical hollow-core (QEHC) with triangularly arranged hexagonal holes in fiber cladding. Birefringence, confinement loss (CL) and GVD of the proposed

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QEHC-PBGF are investigated via numerical simulations. We also explore the influence of geometric parameters surrounding the central air-core on polarization-maintaining property and confinement ability.

2. Fiber structure and simulation parameters

The cross-section and defined structural parameters of the 4-cell QEHC-PBGF are shown in Fig. 1(a) and (b), respectively. The representations utilized here are the same as those in Ref. [25]. The fiber cladding is a triangular arrangement of hexagonal holes with rounded corners. Air-core is formed by omitting the central 4 capillaries in order to create a mode-guiding defect and intentionally induce the anisotropy of core shape thus achieving high birefringence. The hole-to-hole distance (i.e. lattice pitch) and the hole diameter are defined as Λ and d, respectively. The six corners of each hole are rounded with circles of diameter d_h. Surrounding the area of central core, the thickness of every strut is $t_c = (\Lambda - d)/2$ to reduce the coupling between core modes and surface modes [26]. In our numerical simulations, the values of Λ and d are respectively fixed at 750 μm and 0.98Λ, and the curvature at every hexagonal hole is chosen to be 0.66Λ to ensure that the central frequency of the transmission bandwidth is roughly located at 1 THz. The fillet diameter at the polished side is denoted as d_r and the boundary of central air hole is rounded by circles of d_c. d_r and d_c are chosen to be 0.2Λ and 0.5Λ, respectively.

Zeonex is considered as the background material for the manufactural feasibility and the ultra-low dielectric absorption in THz regime. The material absorption loss of Zeonex is 0.14–0.21 cm^{-1} over 0.2–1 THz [27]. The refractive index of air is set to be 1 and regarded as nondispersive and lossless in our simulations. The dispersive complex refractive index of Zeonex is from Ref. [27] and the real refractive index is 1.52 at around 1 THz. The fiber characteristics are numerically simulated by finite element method with the COMSOL software package and a perfectly matched layer is implemented surrounding the cladding.

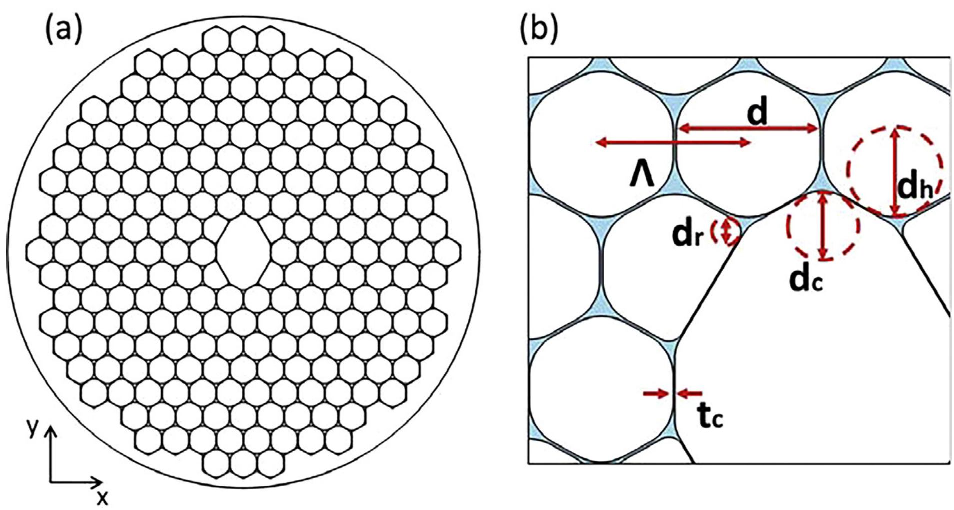

Fig. 1. (a) Cross-section of the 4-cell QEHC-PBGF in numerical simulations; (b) Definition of structural parameters.

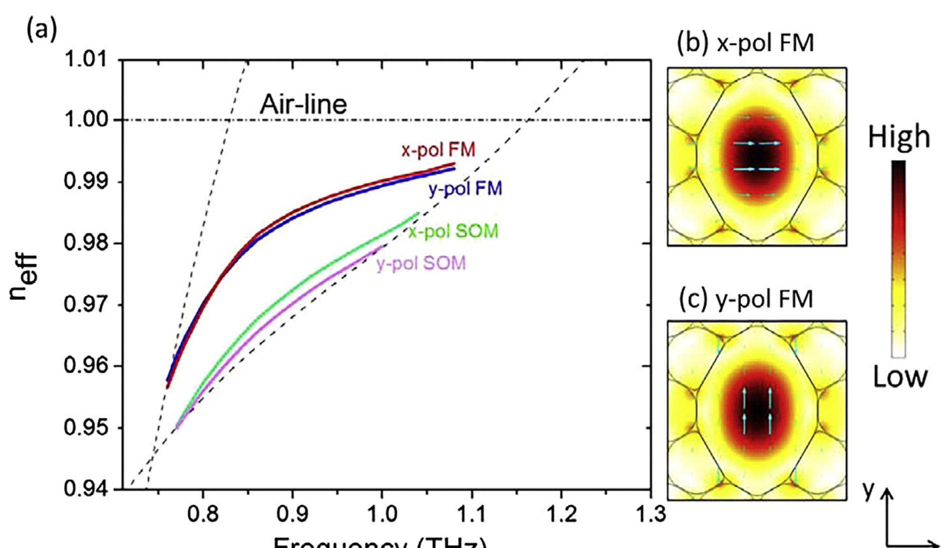

Fig. 2. (a) Photonic bandgap map (dashed curves) and modal n_{eff} (solid curves) of 4-cell QEHC-PBGF; Modal fields of (b) x-pol FM and (c) y-pol FM at 0.9 THz.