Optical Fiber Technology 26 (2015) 163–171

Contents lists available at ScienceDirect

Optical Fiber Technology

www.elsevier.com/locate/yofte

High birefringence rectangular-hole photonic crystal fiber

Guangyu Jiang *, Yanjun Fu, Yan Huang

School of Measuring and Optical Engineering, Nanchang Hangkong University, Nanchang 330063, China

ARTICLE INFO

Article history:
Received 13 April 2015
Revised 6 July 2015
Available online 11 September 2015

Keywords:
Birefringence
Rectangular-hole
Nonlinear optic

ABSTRACT

A novel highly birefringent photonic crystal fiber (PCF) based on rectangular-hole is proposed and numerically analyzed by employing the finite-element method. The proposed PCF can achieve birefringences similar to those of the elliptical-hole PCF and rhombic-hole PCF. The properties of such PCFs are investigated for different parameters related to rectangular-holes, including the rectangular-hole pitch, length and the length and width ratio. The results show that the birefringence of rectangular-hole PCF reaches the magnitude of 10^{-3} which fulfills the requirements of high precision applications in optical systems, which will find application in nonlinear optics.

1. Introduction

Photonic crystal fibers (PCFs) [1,2], also known as microstructured or holey fibers, consisting of a periodic distribution of air holes along the longitudinal axis and a defect region in the center, have recently generated great interest over the past decade for potential applications in fiber sensors [3–5], fiber lasers [6–8], and nonlinear optics [9–11]. PCFs possess better flexibility in designing of the structure and achieve excellent properties, such as birefringence [12–14], endless single mode [15,16], dispersion [17,18], and effective mode area [19–21]. In recent years, with the rapidly increasing requirements of fiber properties applied in high precision and velocity optical information transmission, plenty of PCFs have been designed to fulfill the rapid development of high performance. However, Low birefringence is the main factor to restrict the applications of the existing single mode fibers (SMFs), so how to enhance the birefringence of fibers has become a hotspot. Investigations on PCFs indicate high birefringence can be obtained by disrupting the structure symmetry in the cross-section of fibers. Zhang et al. proposed a type of micro-structural core PCFs, whose birefringence property can achieve a magnitude of 10^{-3} [22]. Xu et al. proposed a new type of photonic crystal fiber (PCF), which consists of air cores arrayed with pentagonal core and hexagonal cladding, the birefringence of this PCF reaches the magnitude of 10^{-3} [24]. Generally, most PCFs are formed by use of circular airholes in the cross section, and high birefringence is introduced by the asymmetry of the fiber core (e.g., with a double defect or a triple defect in the fiber core). However, there are also a few reports about highly birefringent PCFs that use elliptical air-holes in fiber cladding [21,25–28], which can achieve high birefringence even be up to the order of 10^{-2}. Very recently, high birefringence induced by rhombic air-hole is numerically analyzed by using the finite-element method. The results showed that the birefringence of the rhombic-hole PCF is relatively larger than that of an elliptical-hole PCF with the same air-filling fraction ($f = 0.0375$) when the ratio of the rhombic-hole diagonal length is equal to the elliptical-hole ellipticity. Medjouri et al. proposed a solid core photonic crystal fiber (PCF) with square air holes can achieve high birefringence of 2.5×10^{-3} [23]. In this paper, we introduce a few PCFs with rectangular-holes, analyze numerically their birefringence, and investigate the birefringences of rectangular-hole, elliptical-hole and rhombic-hole PCFs. The results show that rectangular-hole PCFs can achieve the similar birefringence properties with the elliptical ones and rhombic ones, the different parameters of hole shape influence significantly the birefringence.

2. Structure of rectangular-hole photonic crystal fiber

The cross section of the rectangular-hole PCF are illustrated in Fig. 1. The rectangular air holes are arranged in a triangular lattice in the background of the silica. The fibers are characterized by the pitch Λ, the length and width ratio $\alpha = a/b$, where b and a are the lengths and widths of the rectangular-hole, respectively. In addition, the refractive index of the background silica is set as $n = 1.45$.

3. Properties of rectangular-hole PCF

In order to compute the field distribution and its modal effective indices, one uses the finite-element method, which is specially

* Corresponding author.
E-mail address: jgy579@126.com (G. Jiang).

http://dx.doi.org/10.1016/j.yofte.2015.08.010
1068-5200/

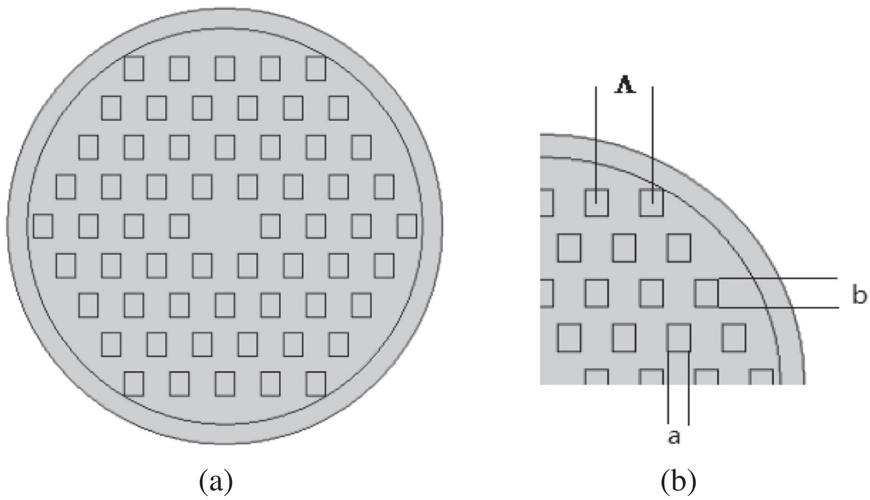

Fig. 1. (a) Cross section of the rectangular-hole PCF (b) one-quarter of rectangular-hole PCF cross section.

designed for the analysis of general dielectric waveguide geometries and has been justified to be more flexible and reliable than other known techniques [29]. In general, the phase birefringence of a PCF is defined as $B = |n_{xeff} - n_{yeff}|$, where n_{xeff} and n_{yeff} are the effective indices of the *x*-polarized and *y*-polarized fundamental mode of the PCF. The effective index and birefringence of PCFs are relative to rectangular-hole shape and size, hole spacing, and working wavelength. To check the influence of air-hole size on the fiber birefringence. Fig. 2 shows the effective indexes of the *x*-polarized and *y*-polarized fundamental mode and birefringence of the rectangular-hole PCFs with different hole pitches $\Lambda = 2$, 3, 4 μm, but with fixed $b = 1$ and $a = 0.6$. As shown in Fig. 2(a),the effective indexes of the *x*-polarized and *y*-polarized fundamental mode decrease over the range of wavelengths, and for a larger hole pitch, the rectangular-hole PCFs have a higher effective index. We also determined that *x*-polarized modes have a higher effective index than the *y*-polarized modes for the rectangular-hole PCFs, the differences of the *x*-and *y*-polarization mode at the long wavelength are more larger for a smaller hole pitch. Therefore the rectangular-hole PCFs achieve high birefringence with the wavelength for a smaller hole pitch. In Fig. 2(b), the birefringence of the rectangular-hole PCF increases with the hole pitch at the whole wavelength range from 0.5 μm to 2 μm, the reason for which is that a larger hole pitch Λ relatively increases the difference between the effective indices of *y*- and *x*-polarization modes. As shown in Fig. 2(b), the birefringence increases from 1.08×10^{-3} to 1.43×10^{-3} at $\lambda = 1.55$ μm, when the area of the air holes is enlarged from 2 μm to 4 μm.

For PCFs, it is important for different fiber structure parameters to realize more characteristics. Therefore, it is necessary to discuss influence of the structure parameters on birefringence in rectangular-hole PCFs. We investigate the influence of the geometric parameters *b* and α on the birefringence for rectangular-hole PCFs, as shown in Fig. 3. Fig. 3 illustrates the birefringence as a function of α and *b*. The birefringence always increases with the increasing of λ, but the rates of increase are different for the rectangular-hole PCFs with different parameters. When $\Lambda = 2.3$ μm, $\alpha = 0.2$, and *b* varies from 1 to 0.4, the variation of the birefringence is shown in Fig. 3(a). At the beginning, the difference of the *x*- and *y*-polarization mode is very small, and then it increases with the increasing of λ; however the difference of the *x*- and *y*-polarization mode changes differently when the wavelength changes from 0.6 μm to 1.3 μm. When $\lambda > 1.3$ μm, the bigger the length of the rectangular-hole is, the larger the

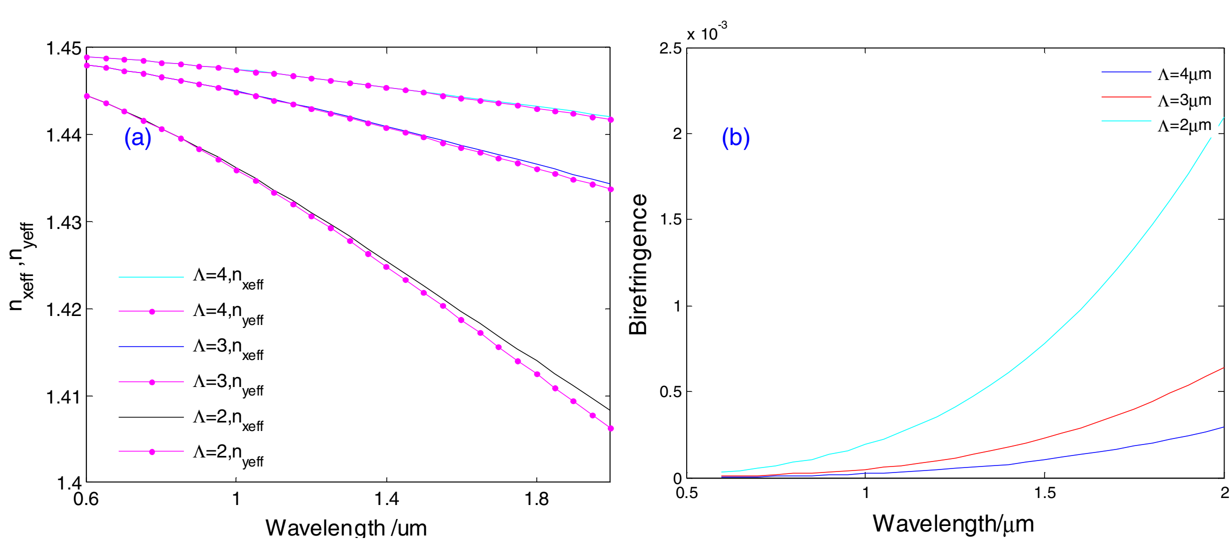

Fig. 2. Effective indexes (a) and birefringence (b) as a function of wavelength for two orthogonal polarization modes of the rectangular-hole PCFs with different hole pitches.