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High birefringent rectangular-lattice photonic crystal fibers with low confinement loss employing different sizes of elliptical air holes in the cladding and the core

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ABSTRACT

Based on the full-vector finite element method with anisotropic perfectly matched layers, modal birefringence and confinement loss for the fundamental mode in rectangular-lattice photonic crystal fibers with different sizes of elliptical air holes in the cladding and the core are investigated numerically. The results show that the modal birefringence in this proposed photonic crystal fibers can be up to 5.64×10^{-2} at the wavelength of 1.55 μm. Moreover, when the birefringence is higher than 4×10^{-2}, the confinement loss of *x*-polarized mode can be kept less than 0.005 dB/km at 1.55 μm. It means that the tradeoff between the high birefringence and the low confinement loss is overcome.

1. Introduction

In the past decade, photonic crystal fibers (PCFs) have been extensively studied due to their many unique properties, such as flat dispersion [1,2], endlessly single-mode operation [3], large mode area [4], high nonlinear coefficient [5], high birefringence [6–9], low confinement loss (CL) [10], and so on. Among the features of PCFs, birefringence and CL are two of the most interesting characteristics. So far, there are many methods to achieve high birefringence in index-guiding PCFs. A common approach is realized by exploiting the anisotropy in PCFs. The anisotropy in PCFs can be introduced by using elliptical-hole [11–14], rhombic-hole [15], squeezed lattice, etc. [16,17]. Another effective way to achieve high birefringence is to introduce asymmetry near the fiber core [6,18,19]. However, in order to obtain higher birefringence, it often needs to reduce lattice length, which induces high leakage loss. Thus, the high birefringence is usually accompanied with poor energy confinement.

In this paper, a novel highly birefringent rectangular-lattice PCF with low confinement loss is proposed. The cladding of proposed PCF is composed of two different sizes of elliptical air holes. In the core region, there are five small elliptical air holes (to provide high birefringence), one of them lies in the center of the core, and the remaining holes are arranged in a rectangular array. The optical properties of the fundamental mode of the fiber structures with different air hole sizes and lattice widths within the wavelengths ranging from 1.4 μm to 1.6 μm are numerically investigated. We find that the modal birefringence in this proposed PCF can be up to 5.64×10^{-2} at 1.55 μm. Furthermore, another interesting finding is that, when the birefringence is higher than 4×10^{-2}, the confinement loss of *x*-polarized mode can be kept less than 0.005 dB/km at 1.55 μm. It means that the tradeoff between the high birefringence and the low loss is overcome.

2. Influence of the geometric parameters on birefringence and confinement loss

The proposed PCF structure used in our simulation is depicted in Fig. 1. The fibers are characterized by the area S (S_1, S_2, and S_3 are the areas of the big, small hole in the cladding and the small hole in the core, respectively), the pitch Λ (Λ_x and Λ_y are the distances between the adjacent large holes or the adjacent small holes in the corresponding *x*-direction and *y*-direction in the cladding, Λ_{x1} and Λ_{y1} are the distances between the adjacent small holes in the corresponding *x*-direction and *y*-direction in the core), and the ellipticity ratio $\eta = b/a$, where b and a are the lengths of the major and minor axes ($\eta_1 = b_1/a_1$, $\eta_2 = b_2/a_2$ and $\eta_3 = b_3/a_3$ are the ellipticity ratios of the big, small hole in the cladding and the small hole in the core, respectively). The *x*-direction and *y*-direction ratio of the pitch in the cladding is defined as $\gamma = \Lambda_x/\Lambda_y$, so it is the same in the core $\gamma_1 = \Lambda_{x1}/\Lambda_{y1}$. There are only four big elliptical air-hole rings in the calculations. In addition, the refractive index of the background silica is set as $n = 1.45$.

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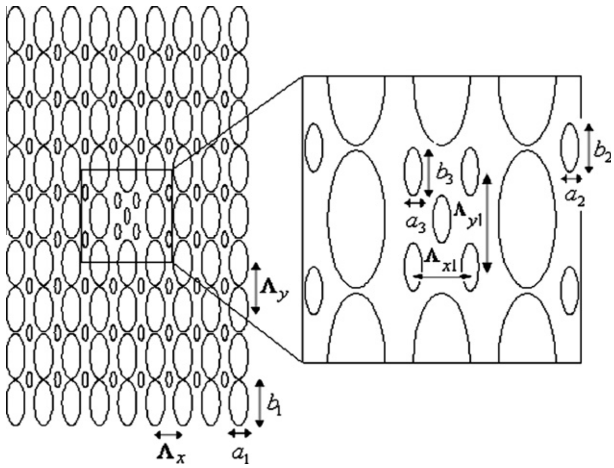

Fig. 1. Cross-sectional view of the proposed PCF.

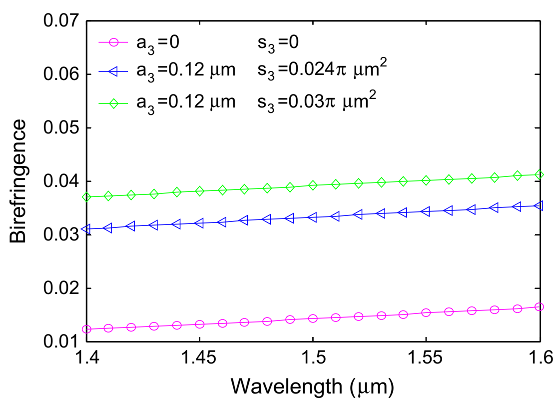

Fig. 2. The birefringence for case with $a_3 = 0.12$ μm.

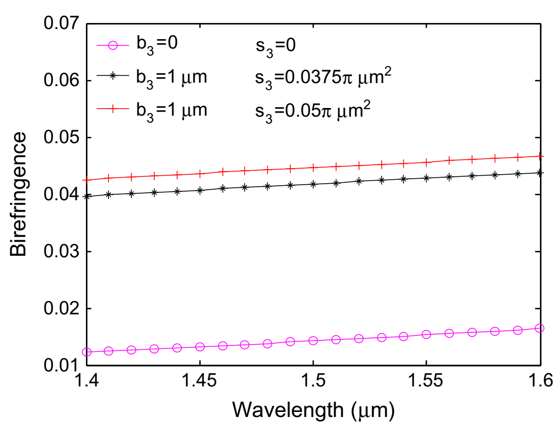

Fig. 3. The birefringence for case with $b_3 = 1$ μm.

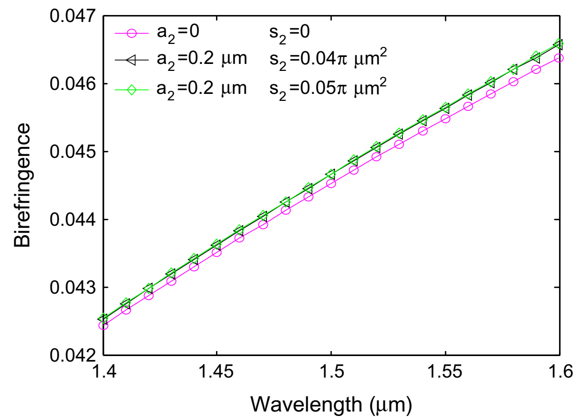

Fig. 5. The birefringence for case with $a_2 = 0.2$ μm.

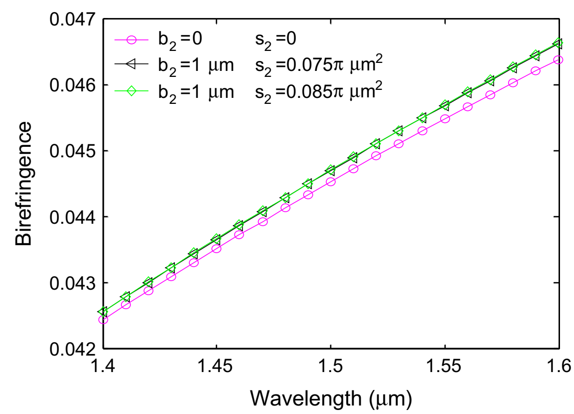

Fig. 6. The birefringence for case with $b_2 = 1$ μm.

In order to compute the field distribution and its modal effective indices, one can use a full-vector finite element method. Precisely, we have used the commercial software Comsol, to solve Maxwell equations on the fiber structure, and output the complex eigenvalues, as well as the modes profiles. In particular, this enable us, through the use of PML boundary conditions, the complex modal effective index (n_{eff}) can be obtained, and then, the modal birefringence and the confinement loss can be calculated [20].

First of all, the influences of the small elliptical holes in the core on the modal birefringence and the CL are studied. Here, fixed $\Lambda_x = 1.26$ μm, $\Lambda_y = 3.06$ μm, $a_1 = 1.2$ μm, $b_1 = 3$ μm, $a_2 = 0.2$ μm, $b_2 = 0.6$ μm, $\Lambda_{y1} = 2$ μm and $\gamma_1 = 0.4$ are chosen for our simulation. Figs. 2 and 3 show the birefringence for fibers with $a_3 = 0.12$ μm and $b_3 = 1$ μm respectively. According to the figures, we can learn that, if the fiber core is a solid core, the birefringence at 1.55 μm

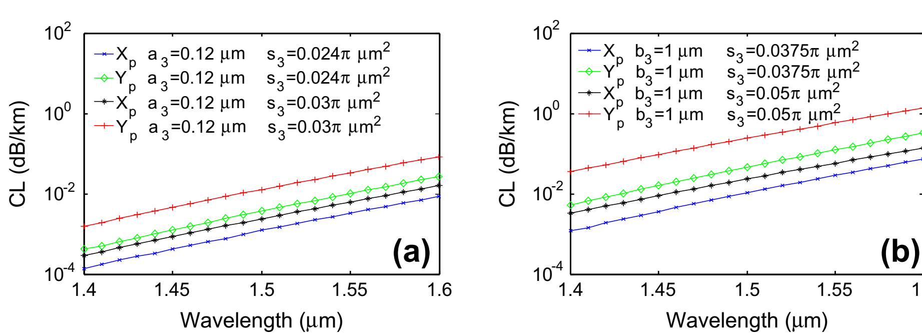

Fig. 4. The CL for the case with $a_3 = 0.12$ μm (a) and $b_3 = 1$ μm (b).