Design of polarization-maintaining photonic crystal fiber with high birefringence

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***Abstract*—We design a polarization-maintaining photonic crystal fiber (PCF) with elliptical air-holes. The asymmetric geometric structure is proposed for the polarization-maintaining PCF with higher birefringence.**

I. INTRODUCTION

Recently, photonic crystal fibers (PCFs) have been widely used and researched due to their superior properties better than conventional fibers, such as low nonlinearity, endlessly single-mode operation, larger mode area, and high birefringence [1-3]. These properties provide scaling potential for fiber laser and amplifier systems. They consist of an ordered array of air-holes running along its length. Besides, many experiments and applications require polarization-maintaining fibers [4]. The system control of the polarization state is most important. Two kinds of the polarization-maintaining fiber have developed and discussed their feasible design. One is utilized elliptical core or elliptical cladding fibers [5]. The other is utilized stress-applying parts (SAP) inside the fiber [6]. Thus, the two kinds of fiber exhibit the birefringence on the order of 10-4 can be realized.

In this paper, we proposed an improvement of PCF to increase the birefringence on the order of 10^{-3}. One of analysis methods corresponds to finite-element method (FEM). This method respects the sufficient reliability, efficiency, and accuracy for the PCFs.

II. POLARIZATION-MAINTAINGING FIBER DESIGN

The cross sections of the proposed PCFs are shown in Fig. 1, where Λ is the hole pitch and d is the hole diameter. The large holes indicate d_1 on the opposite sides of the core, which can introduce the fiber structure to obtain the birefringence.

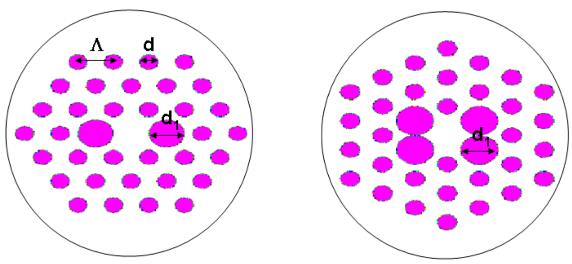

Fig. 1. The proposed PCF structures: (a) type1 and (b) type 2.

First we proposed the two PCF structures with hexagonal lattice air-holes in cladding. The background index of the cladding is chosen for silica (n=1.45). They also have the same parameters of hole pitch (Λ=5μm), hole diameter (d=2.65μm), and large hole diameter (d_1=5μm). We expected that the two different PCFs have the refractive indices in x- and y-directions. These modes are called slow- and fast-axis. The birefringence is calculated by the following equation:

$$B = \left| n_{eff}^{x} - n_{eff}^{y} \right| \tag{1}$$

where n_{eff} are effective indices of two polarized modes in fundamental. The numerical result of the dependence of the birefringence on the relative wavelength is shown in Fig. 2. The birefringence of the type2 fiber is significantly higher than type1 fiber. As a result, the birefringence of type2 is 5.62×10^{-4} at the wavelength of 1.55μm.

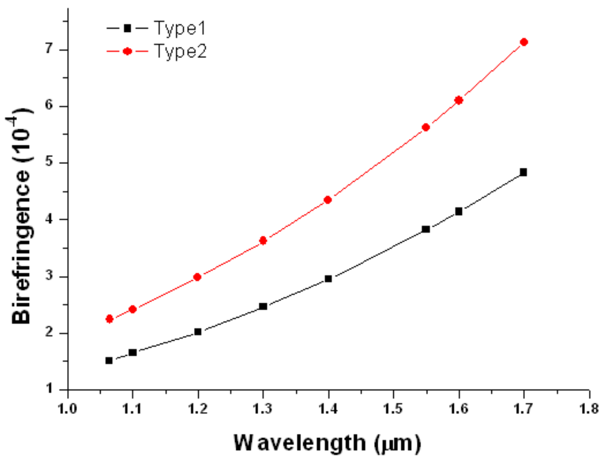

Fig. 2. Birefringence of the two PCF structures.

III. OPTIMIZATION DESIGN

In order to obtain higher birefringence, we introduce elliptical holes on the opposite sides of the core to improve type2 fiber, as shown in Fig. 3. The ellipticity is defined by the equation:

$$E = \frac{b}{a} \tag{2}$$

where a and b are radii of air-hole in x- and y-direction. The different elliptical ratios are studied and plotted in Fig. 4. The improved PCF is calculated at the wavelength

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of 1.55μm, which can achieve the birefringence on the order of 10^{-3} until the ellipticity is greater than 12.

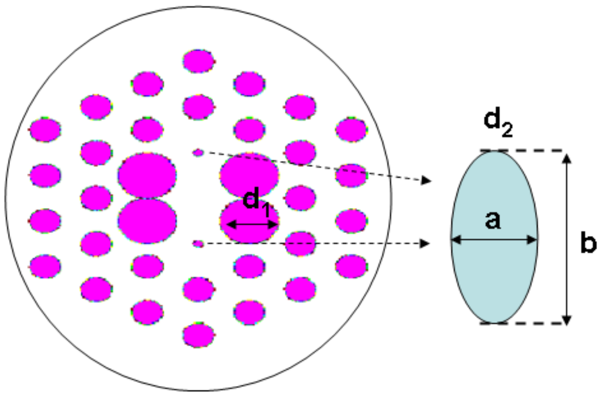


Fig. 3. The improved PCF with elliptical holes.

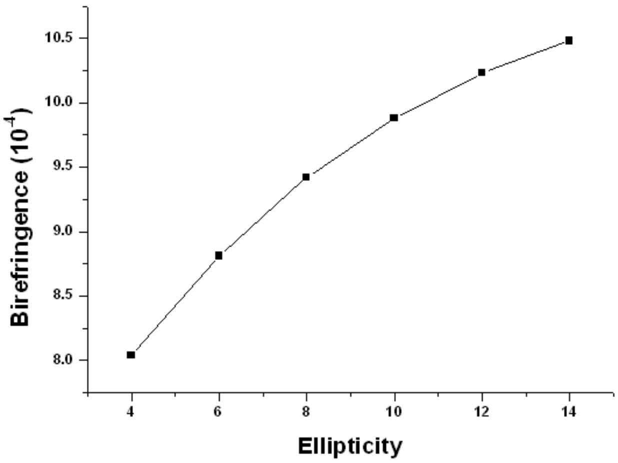


Fig. 4. Birefringence in the improved PCF with different elliptical holes.

To solve the confinement loss of the improved PCF, it is necessary to use a perfectly matched layer (PML). PML is mainly to absorb its boundaries and avoids the reflection of electromagnetic waves. The confinement losses of the polarization mode as a function of elliptical holes are shown in Fig. 5.

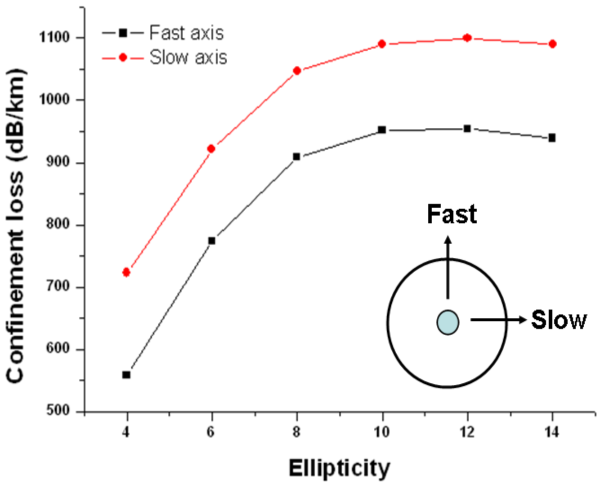
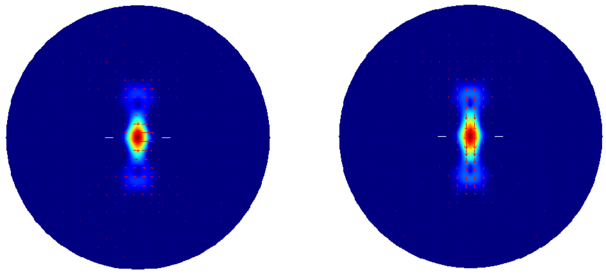


Fig. 5. The confinement losses of the improved PCF with different elliptical air holes.

The cconfinement loss of slow-axis is obviously higher than fast-axis due to large size difference between x- and y-direction. The confinement loss is less than 1.1dB/km for the improved PCF. The electric field distributions of two polarization modes are shown in Fig. 6. Such design could lead to important applications in PCFs of high birefringence.



(a) (b)

Fig. 6. Electric field distributions of the polarization mode for (a) x-polarization and (b) y-polarization.

IV. Conclusions

In this paper, we design a polarization-maintaining PCF with elliptical air-holes. This significantly increased the birefringence by introducing elliptical holes on the opposite sides of the core. Finally, the proposed technology provides a promising PCF with high birefringence.

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