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Ultrahigh birefringence index-guiding photonic crystal fiber

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Abstract: We reported an ultrahigh birefringence PCF with a germanium-doped elliptical core, which is fabricated in our lab using the stack-and-draw method, and an ultrahigh birefringence of 1.1×10^{-2} is obtained experimentally via FBG and Sagnac loop.
OCIS codes: (*060.2280*) Fiber design and fabrication; (060.5295) Photonic crystal fibers; (060.3735) Fiber Bragg gratings

1. Introduction

Photonic crystal fibers (PCFs) have been attracting great interest in the research community since the first endlessly single-mode PCF was reported in 1997 [1]. To realize single polarization device with zero polarization mode dispersion, polarization-maintaining fibers (PMFs) with high birefringence are needed. The PCF technology is far more superior in producing PMFs. High birefringence can be achieved simply by introducing two large air holes close to the core of conventional single-mode PCF. Most PMFs exhibit birefringence in the order of 10^{-4} to 10^{-3}. For the commonly used commercial PM-1550-01™ fiber, the birefringence is $\sim3.9\times10^{-4}$. The highest birefringence reported for fabricated index-guiding PCFs was in the order of 10^{-3} [2,3]. It should be noted that the highest group birefringence reported were found in a photonic bandgap fiber (0.025 at the wavelength of 1550nm), achieved via elliptical air-core [4]. However, such fiber does not allow the inscription of fiber gratings in its core. There are also some other designs of PCF to obtain high birefringence that can reach up to 10^{-2}, such as the elliptical-like holes structure [5]. However, the structure is difficult to fabricate compared to the two large holes PCF and no fabricated elliptical-like holes fiber was reported.

In this paper, we report on an ultrahigh birefringence index-guiding PCF (with two large holes) with measured phase modal birefringence of $\sim1.1\times10^{-2}$ and group birefringence of $\sim1.25\times10^{-2}$. The phase modal birefringence was measured by inscribing FBG in Ge-doped core, resulting in two distinct Bragg peaks separated by over 12 nm. A Sagnac loop with a very short length was set up to measure the group birefringence. The experimental value of birefringence was confirmed by simulation as well, giving the values of 1.4×10^{-2} for B_p and $\sim1.5\times10^{-2}$ for B_g.

2. Fabrication of Hi-Bi PCF

The Hi-Bi PCF was fabricated in-house using the stack-and-draw technique on a fiber drawing tower (Nextrom OFC20). The fabrication process is similar to the fabrication method conducted by us previously for a twin-core PCF [6]. Capillaries with diameter of 1.6 mm were firstly drawn from a silica tube that has an outer diameter of 44 mm and inner diameter of 17.6 mm. Meanwhile, pure silica rods with different diameters were drawn for stacking. During stacking, a germanium-doped rod (1 mm in diameter) was used to replace the center capillary and will eventually become the core of the Hi-Bi PCF. Two large capillaries, with a diameter of 1.6mm and air fraction of 0.76, were inserted adjacent to the core. The stacked preform was then drawn into canes with a diameter of 1.6 mm. One cane was chosen and inserted into a jacket tube of 7 mm in diameter, which was stretched from a silica tube with inner and outer diameters of 4 mm and 12 mm, respectively. This ensemble was then drawn into fiber at the temperature of 1870 ˚C. Lower temperature and vacuum control were used to enlarge the air holes, especially the two big holes so that an elliptical core can be formed to obtain high birefringence.

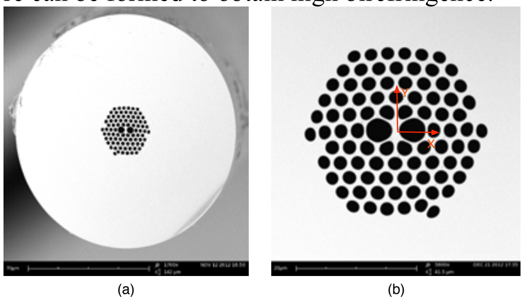

Fig. 1 The SEM photos of the cross-section of the Hi-Bi PCF

Fig.1 shows the SEM photos of the fabricated fiber. x and y denotes the fast and slow axis respectively. The outer diameter of the fiber is ~125μm. The small holes have diameter of ~2.35μm and pitch of ~3.04μm. The two holes adjacent to the core were enlarged with size of 4.3μm×3.81μm. Consequently, the core became elliptical and has a dimension of ~3μm×1μm. The measured propagation loss of the PCF is ~0.2dB/m. And the splicing loss of the fiber to SMF28 is ~2.1dB.

3. The measurement of birefringence

Simulation of the Hi-Bi PCF was performed using finite element method. The refractive index for core is set as 1.47 and 1.444 for the silica. Fig. 2(a) illustrates the phase modal birefringence (B_p) as a function of different wavelength. It can be seen that the birefringence is in the order of 10^{-2} for wavelengths beyond ~1300nm. The effective refractive indices for fast and slow axis at 1550nm are 1.370937 and 1.384772, respectively, showing a phase birefringence (B_g =Δn) of 1.4×10^{-2}. High birefringence was confirmed by writing FBG in the fiber using the phase mask technique. Two phase masks were used separately in two measurements with pitches of 1072.21 nm and 1110.3 nm. Fig. 2(b) shows the reflection spectra of two FBGs. The two reflective peaks, corresponding to LP_{01-x} and LP_{01-y} are separated by more than 12nm, much larger than that of FBG inscribed in commercial PM-PCF (<1nm) [7]. The large peak separation indicates ultrahigh B_p of 1.1×10^{-2}, which is close to the simulation value.

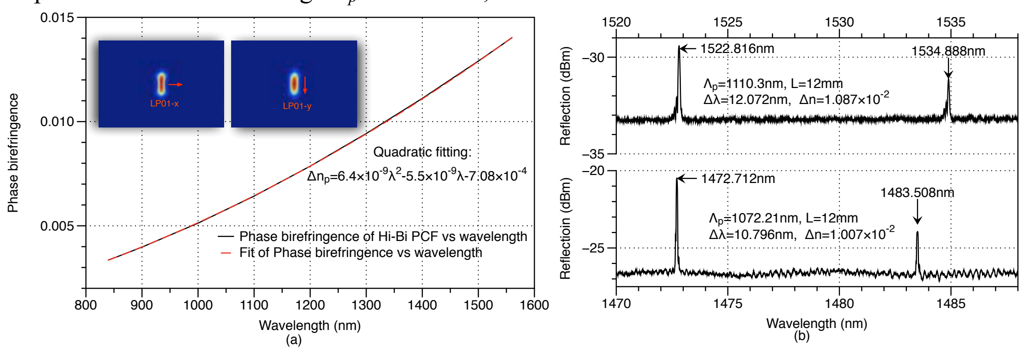

Fig. 2 (a) The phase modal birefringence of Hi-Bi PCF as a function of wavelength, insets show the intensity profile of LP01-x and LP01-y (b) Reflection spectra of FBGs written on the fiber

Fig. 3(a) illustrates the group birefringence (B_g) as a function of wavelength and the inset shows the relationship of B_p and B_g. The curve shows that the Hi-Bi PCF also has ultrahigh B_g, larger than 10^{-2} beyond the wavelength of 1200nm. The B_g at 1550nm is calculated to be 1.5×10^{-2}. To confirm this, a Sagnac interferometer was constructed using the Hi-Bi PCF to determine B_g. Due to the ultrahigh group birefringence, PCF with a short length of 5.5cm is sufficient to obtain a reasonable fringe spacing. The transmission of Sagnac loop is shown in Fig. 3(b), with a spacing of ~3.48nm between two adjacent minimums. Therefore, the measured group birefringence is 1.255×10^{-2}, which is reasonably close to the simulation value.

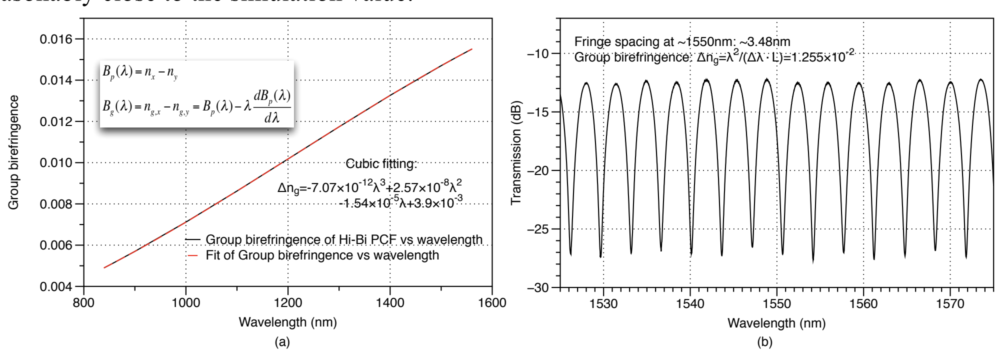

Fig. 3 (a) The group birefringence of Hi-Bi PCF as a function of wavelength and (b) the transmission spectrum of Sagnac interferometer using Hi-Bi PCF.

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