Optik 125 (2014) 6757–6760

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Highly birefringent photonic crystal fiber polarization splitter made of soft glass

Hao Rui*

College of Sciences, Yanshan University, Qinhuangdao 066004, PR China

ARTICLE INFO

Article history:
Received 27 November 2013
Accepted 6 July 2014

Keywords:
Photonic crystal fiber
Polarization splitter
High birefringence

ABSTRACT

A soft glass dual core polarization splitter based on highly birefringent photonic crystal fiber (PCF) is proposed and the full vector finite element method (FEM) is employed to analyze the impacts of structural parameters on birefringence and the coupling length, and simulation results show that high birefringence on the order of 10^{-2} can be obtained at 1.55 μm, moreover, hole size, hole pitch and elliptic ratio all affect birefringence and the coupling length. Based on these results, the PCF's structure is optimized to realize a polarization splitter of 282 μm whose largest extinction ratio is around −45.42 dB at 1.55 μm. Meanwhile, the bandwidth at the extinction ratio of −10 dB is about 90 nm, and around 32 nm at −20 dB.

1. Introduction

In recent years, there has been a significant research interest in PCFs [1,2] due to their unusual and excellent optical properties, such as a wide wavelength range of single-mode operation [3,4], controllable effective modal area [5–7], tailorable dispersion [8] and high birefringence [9,10]. One of these special features is high birefringence, which is of great importance in developing polarization maintaining fibers, single polarization single mode fibers and so on. Bin [11] proposed a highly birefringent PCF structure composed of rhombic holes, in which high birefringence on the order of 10^{-3} at 1.55 μm is realized. Abdur Razzak [12] reported high birefringence of 10^{-2} at 1.55 μm in an octagonal PCF consisting of circular and elliptical air holes. Jiahong [13] presented a hexagonal structure with selectively filling liquids into some air holes and high birefringence of 10^{-3} can be reached at 1.55 μm. Jianfei [14] numerically simulated a PCF structure with elliptical air holes of different sizes arrayed in rectangular lattice and high birefringence of 10^{-2} is obtained at 1.55 μm.

Polarization splitters are important components for many optical applications, such as coherent optical communication systems and fiber optical sensors. Novel polarization splitters based on PCFs with various structures have been reported. Lorenzo [15] proposed a polarization splitter based on a square lattice PCF, which comprises three asymmetrical cores. Dong [16] reported a polarization splitter based on all solid dual core PCF and the full vector finite element method was employed to analyze characteristics of the splitter. Wenliang [17] presented a three core PCF polarization splitter with a bandwidth of 400 nm, and two fluorine-doped cores and an elliptical modulation core are introduced in this structure.

At present, soft glass PCFs have attracted widespread attentions due to some advantages of soft glass materials, for example, they allow the transmission of light in a wide infrared wavelength range and they have higher linear and nonlinear refractive indexes, moreover, their typical melting temperature is much lower than that of silica. Qin [18] reported wide and flattened supercontinuum generation in zero-dispersion-wavelength-decreasing tellurite. Hameed [19] presented a PCF design made of soft glass SF57 with high birefringence of 10^{-2} at 1.55 μm. Jiang [20] investigated a hollow core SF6 lead-silicate glass PCF in which the single mode guidance of light is realized in a wavelength range from 750 nm to 1050 nm with a large modal area. Liu [21] proposed a tellurite glass dual core PCF splitter whose bandwidth is around 20 nm at the extinction ratio of −10 dB. Shuguang [22] numerically studied a polarization splitter based on ZnTe tellurite glass three core PCF in which a bandwidth of 20 nm at the extinction ratio of −20 dB is achieved.

In this paper, a novel dual core polarization splitter based on highly birefringent soft glass PCF is proposed and the finite element method is used to calculate the effective indexes of the dual core PCF. Moreover, the impacts of structural parameters on birefringence and coupling length are numerically analyzed, and by adjusting the structural parameters high birefringence and short coupling lengths can be obtained.

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* Tel.: +86 13722577675; fax: +86 3358057027.
E-mail addresses: hrhit@126.com, hrysu@163.com

http://dx.doi.org/10.1016/j.ijleo.2014.07.096
0030-4026/

2. The proposed PCF's structure and theory

Fig. 1 illustrates the structure of the dual core soft glass PCF that is made of schott glass SF6 whose refractive index at 1.55 μm is 1.76. All air holes are arranged in a square lattice and Λ is the hole pitch in the cladding. d_0 and d are diameters of air holes in the center and in the cladding, respectively. A and B denote two symmetrical cores of the PCF and a and b represent the major axis and minor axis of the four elliptical air holes around the two cores, respectively. The elliptic ratio η of these elliptical holes is defined as $\eta = b/a$.

The effective index of the proposed PCF is calculated by FEM and birefringence can be expressed as [23]

$$B = |Re(n_{eff}^{x} - n_{eff}^{y})| \tag{1}$$

where B represents birefringence, Re stands for the real part of the effective index, n_{eff}^{x} and n_{eff}^{y} denote effective refractive indices of the x- and y-polarized fundamental modes, respectively.

According to the mode coupling theory, the total modes can be considered as a superposition of four modes, including the odd modes $E_{odd}^{x,y}$ and the even modes $E_{even}^{x,y}$. And their effective refractive indexes are $n_{odd}^{x,y}$ and $n_{even}^{x,y}$, respectively. The coupling length is defined as [24]

$$L_{x,y} = \frac{\lambda}{2(n_{even}^{x,y} - n_{odd}^{x,y})} \tag{2}$$

where λ is the operating wavelength.

When the powers inputted into one core are $P_{in}^{x,y}$, the output powers $P_{out}^{x,y}$ can be calculated from the following equation [25]

$$P_{out}^{x,y} = P_{in}^{x,y} \cos^2\left(\frac{\pi}{2}\frac{z}{L_{x,y}}\right) \tag{3}$$

where z is the propagation length along the fiber. With the $P_{out}^{x,y}$ obtained, the extinction ratio, ER, can be defined as follows [21]

$$ER = 10\ \log_{10}\frac{P_{out}^{y}}{P_{out}^{x}} \tag{4}$$

3. Numerical results and discussion

The finite element method is applied to calculate the effective refractive index and simulate the distribution of fundamental modes of the PCF, and the distribution of even modes and odd modes are shown in Fig. 2.

The structural parameters in Fig. 1 are as follows: the hole pitch is Λ = 1.2 μm, diameters of air holes in the center and in the cladding are d_0 = 0.4 μm and d = 0.6 μm, respectively, and the elliptic ratio is η = 0.34. In order to analyze impacts of parameters on birefringence, firstly we set some of those parameters as follows: Λ = 1.2 μm, d = 0.6 μm, d_0 = 0.4 μm, and the elliptic ration η is varied from 0.28 to 0.34.

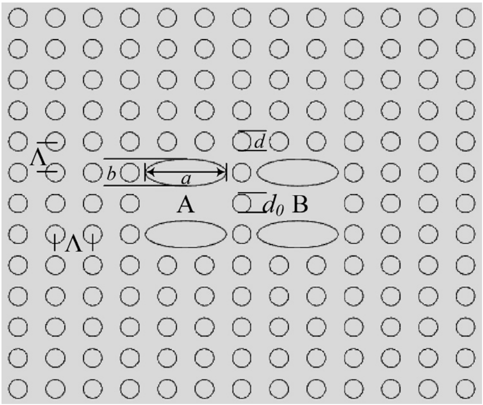

Fig. 1. Cross section of the soft glass dual core PCF.

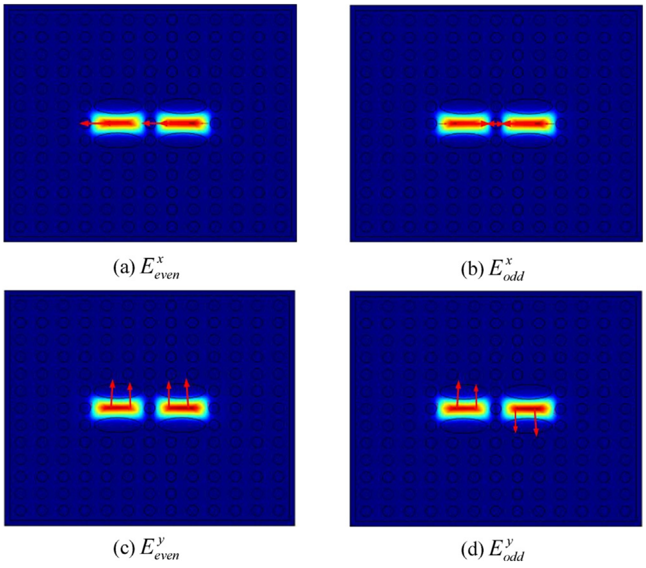
(a) E_{even}^{x} (b) E_{odd}^{x}
(c) E_{even}^{y} (d) E_{odd}^{y}

Fig. 2. Distribution of even and odd components of fundamental modes. (a and b) Even and odd modes of x polarization. (c and d) Even and odd modes of y polarization.

Results in Fig. 3 show that birefringence increases with the increase of elliptic ratio because a larger elliptic ratio can enhance the asymmetry of cores, which results in higher birefringence. Moreover, the birefringence also increases with wavelength increasing and this is because modal fields in a longer wavelength range tend to expand into the cladding, thus the asymmetry of the cladding also plays a part in enhancing birefringence. At 1.55 μm, birefringence is 1.80×10^{-2} for η = 0.34.

Then with the elliptic ratio η fixed as 0.34, we analyze the influence of the central hole's diameter d_0 on birefringence, and the results are shown in Fig. 4.

We can see from Fig. 4 that higher birefringence can be reached with a larger central hole's size d_0 because the increase of d_0 can enhance the asymmetry of the cores, resulting in higher birefringence. At 1.55 μm, the birefringence is 1.80×10^{-2} for d_0 = 0.4 μm, and 2.01×10^{-2} for d_0 = 0.6 μm.

Finally we set some parameters as d_0 = 0.4 μm, d = 0.6 μm, η = 0.34, respectively, and impacts of the hole pitch Λ on birefringence are investigated.

Results in Fig. 5 indicate birefringence increases with the hole pitch decreased and this is because the smaller hole pitch contributes to the asymmetry of the cladding and cores and can lead to

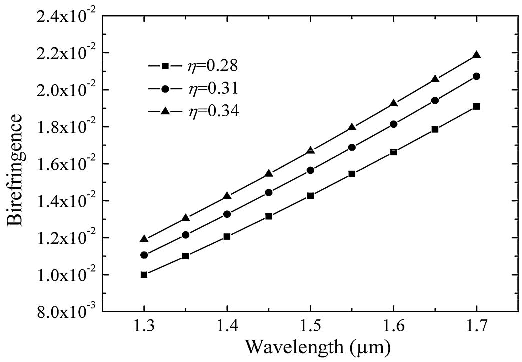

Fig. 3. Birefringence as a function of wavelength with the varied eliptic ratio.