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Polarization splitter based on hybrid-cladding dual-core photonic crystal fibers

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ABSTRACT

This paper proposed a novel type of hybrid-cladding dual-core photonic crystal fiber (PCF) with two larger air-holes around each fiber core. The effects of structural parameters on coupling length were analyzed through full-vector finite element method. A 658 μm-long polarization beam splitter based on the proposed dual-core PCF was completed by birefringence effect. Numerical simulations demonstrated that the polarized light extinction ratio was −42.9 dB at the wavelength of 1.55 μm. The bandwidth arranged over 120 nm when the extinction ratio was lower than −10 dB, which exhibited high performance of splitting one light into two orthogonal polarization states.

1. Introduction

Photonic crystal fibers (PCFs) have elicited considerable research interests since they were proposed by Knight et al. [1], because of their unique properties, such as endless single-mode propagation capability, high birefringence, dispersion management, and high nonlinear coefficient [2–6]. Numerous investigations of theories and experiments have been used to exploit new applications of such fibers. Several groups have reported research based on dual-core PCFs. For example, Saitoh et al. analyzed the coupling characteristics of dual-core PCF couplers [7]. Buczynski et al. studied dual-core PCF with square lattice [8]. Wang et al. studied coupling in dual-core photonic band gap fibers theoretically and experimentally [9]. Li et al. designed a single-polarization single-mode PCF dual-core coupler [10]. Florous et al. proposed a novel approach for designing PCF splitters with polarization-independent propagation characteristics [11]. Xu analyzed the polarization properties of rectangular lattice PCF [12]. Zhang et al. designed a single-polarization wavelength splitter based on PCF [13]. Fu et al. designed two types of dual-core high-birefringence and high-coupling degree PCFs [14]. Moreover, PCFs have a key advantage over their counterparts, that is, PCFs allow the construction of complex dual-core structures because the diameter and position of the air-holes can be selected with great flexibility.

Polarization beam splitters are essential components in varieties of fields, such as optical fiber communications and integrated photonics. Various types of polarization splitters based on PCFs have been proposed in the literature. For example, Saitoh et al. studied polarization splitter in three-core PCFs [15]. Rosa et al. analyzed polarization splitters based on a square-lattice PCF [16]. Chen et al. proposed a broadband polarization splitter based on partial coupling in a square-lattice PCF [17]. Lin et al. studied a novel polarization splitter by using dual-core hybrid PCFs [18]. Liu et al. studied a novel polarization splitter in a ZnTe tellurite glass three-core PCF [19]. Shuo et al. analyzed the characteristics of the polarization splitter on the basis of a tellurite glass dual-core PCF [20].

In this paper, a novel hybrid-cladding dual-core PCF is proposed through the full-vector finite element method (FEM) to numerically simulate the characteristics of dual-core PCFs [21]. By adjusting the geometric parameters, a novel polarization splitter based on the proposed dual-core PCF is obtained.

2. Theory and modeling

Fig. 1 shows the cross-section of the dual-core PCF. It is composed of air-holes for the inner cladding arranged in a rectangular array and the air-hole for the outer cladding arranged in an octagonal array with pitches Λ. The diameter of the air-hole is denoted by d for the outer cladding, d_1 for the inner cladding, d_2 for the larger holes adjacent to the core, and d_0 for the air-hole at the center. The two identical cores, A and B, are formed by replacing the two adjacent air-holes with regular silica, and they are separated by a single

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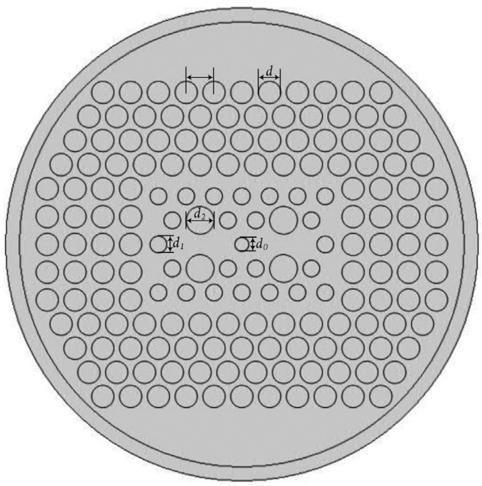

Fig. 1. Cross section of the dual-core PCF.

air-hole, as shown in Fig. 1. The background silica index is assumed to be 1.45.

According to the theory of mode coupling, the total modes can be considered as a superposition of four modes, including the odd modes $E_{odd}^{x,y}$ and the even modes $E_{even}^{x,y}$ [20].

The coupling length for x- and y-polarizations can be expressed as follows:

$$L_{x,y} = \frac{\pi}{\beta_{even}^{x,y} - \beta_{odd}^{x,y}} = \frac{\lambda}{2\left(n_{even}^{x,y} - n_{odd}^{x,y}\right)} \quad (1)$$

where λ is the wavelength of light, $\beta_{odd}^{x,y}$ and $\beta_{even}^{x,y}$ denote the propagation constants of the even and odd modes for x- and y-polarizations, respectively, and $n_{odd}^{x,y}$ and $n_{even}^{x,y}$ are their corresponding effective refractive indices. In the symmetric dual-core PCF, all the energy will transfer from one core into the other and back again as it propagates along the fiber. When the light is incident in the core, the periodic power $P_{out}^{x,y}$ at the outer layer of the cores is defined as

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

where $P_{in}^{x,y}$ is the power of the incident light, z is the propagation length, and $L_{x,y}$ is the coupling length for x- and y-polarizations.

The extinction ratio can be expressed as:

$$ER = 10\log_{10}\frac{P_{out}^{y}}{P_{out}^{x}} \quad (3)$$

3. Coupling characteristic

Fig. 2 shows the variation of coupling length with the wavelength in the proposed dual-core PCFs with $\Lambda = 1.0\,\mu m$, $d = 0.8\,\mu m$, $d_0 = 0.4\,\mu m$, $d_1 = 0.6\,\mu m$, and $d_2 = 1.0\,\mu m$. Fig. 2 shows that the coupling lengths will decrease as the wavelength increases. This phenomenon can be attributed to the fact that the mode field expands and the coupling between the dual-core becomes easy when the wavelength increases. Moreover, the coupling lengths are $L_x = 81.4\,\mu m$ and $L_y = 93.9\,\mu m$ in x and y polarized modes, at the incident wavelength of $\lambda = 1.55\,\mu m$. The coupling lengths are lower than those reported by [18].

The influence of geometric parameters on the coupling length was investigated in the proposed dual-core PCF, which is illustrated in Figs. 3–6.

Fig. 3 shows the dependence of coupling length on the wavelength for different Λ, whose values are 1.0, 1.1, and 1.2. Fig. 3

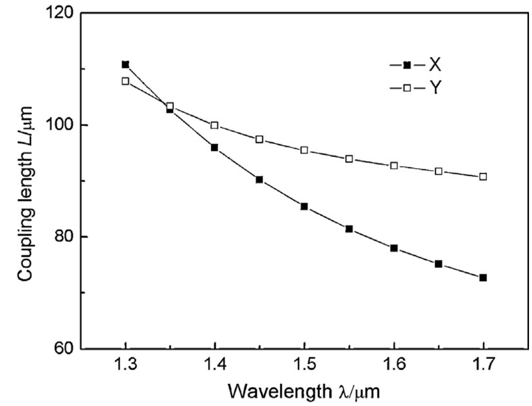

Fig. 2. Coupling length of x polarization and y polarization.

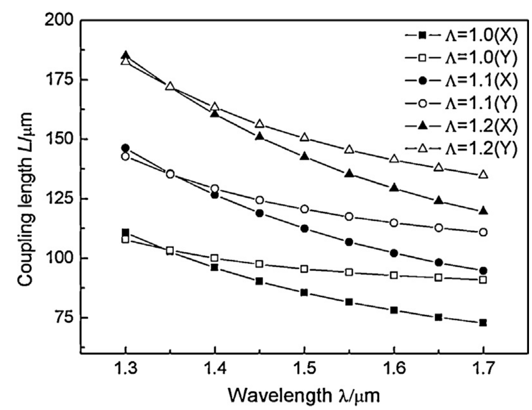

Fig. 3. Coupling length as a function of wavelength under different Λ.

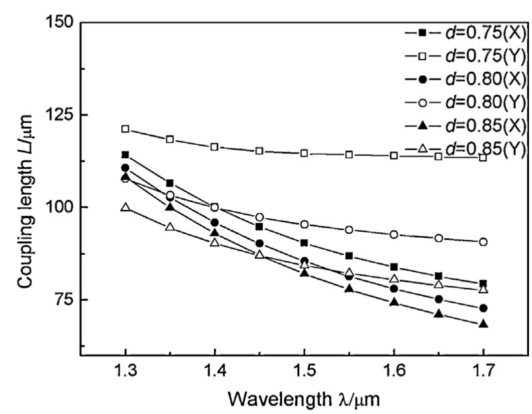

Fig. 4. Coupling length as a function of wavelength under different d.

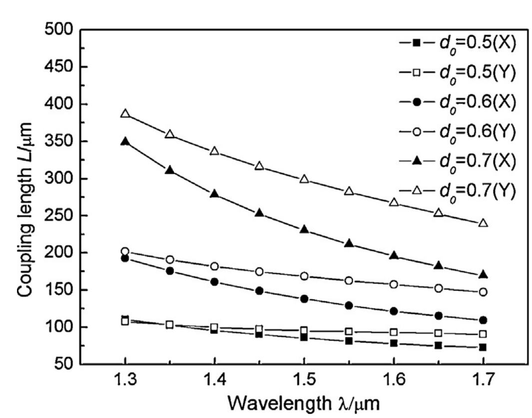

Fig. 5. Coupling length as a function of wavelength under different d_0.