Design of a fiber polarizer based on an asymmetric dual-core photonic crystal fiber*

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We propose a novel optical polarizer based on an asymmetric dual-core photonic crystal fiber (PCF) with triangular lattice air-holes. The fiber is designed as that the effective indices of modes in the two cores are matched at one polarized state but mismatched at another polarized state. As a result, one of the polarization states is coupled to the other core and transferred into a high-order mode. The transmission properties of the polarizer are investigated by the semi-vectorial beam propagation method (SV-BPM). Numerical results demonstrate that a device length of 11.3 mm shows extinction ratio as low as -20 dB with bandwidth as great as 80 nm ranging from 1.51 μm to 1.59 μm.

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It's well known that a conventional single-mode optical fiber supports two linearly polarized fundamental modes. Fiber optical polarizer can eliminate one polarization mode and retain the other one.

Single-mode polarization optical fibers can be used as polarizers. However, they often require a long transmission distance[1-3]. The optical fiber polarization splitters, which can effectively separate the two polarized states, are widely used as optical polarizer. Various kinds of polarization splitters based on photonic crystal fibers (PCFs) have been reported [4-8]. Introducing a high birefrigent core can lead to the increasing difference between the coupling lengths of the two linearly polarized modes. As a result, the two polarized states launching from one core can be separated. The polarization splitter proposed in Ref.[4] shows a splitting ratio better than –11 dB and a bandwidth of 40 nm. Another kind of polarization splitter is designed with asymmetric dual-cores, in which one polarization is entrapped in the incident core while the other polarization can be freely coupled between the two cores[5]. Although the increasing bandwidth can be achieved, the splitter shows low extinction ratio owing to the fact that the modal coupling can not be prohibited completely. Saitoh et al[6] presented a three-core PCF splitter consisting of two given identical cores with two-fold symmetry separated by a core with high birefringence. This polarization splitter has extinction ratio better than –20 dB and a bandwidth of 37 nm. After this, Rosa[7] presented a three-core polarization splitter based on a square-lattice photonic-crystal fiber, in which polarization splitting is realized by separating the input field into two orthogonally polarized beams that are coupled to the horizontal and vertical output ports, respectively. The extinction ratio of the splitter is as low as -20 dB with bandwidth as great as 90 nm.

The above PCF-based polarization splitters generally rely on a high birefringence to realize the separation of the two polarized states. High birefringence generally leads to small and deformed mode areas. Recently, we have presented a numerical simulation of a novel broadband polarization splitter, which is based on an asymmetric dual-core square-lattice photonic crystal fiber[8].

In this paper, we propose a numerical simulation for a new kind of optical fiber polarizer, the performance of which does not rely on the high birefringence of the cores. The dual-core fiber is designed for the polarizers where index-matched coupling can be achieved for one polarization state while only part of energy could be coupled for the other

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polarization state. According to coupled-mode theory[9], the coupling length of the two mismatched modes is shorter than that of the index-matched modes. Therefore, if the coupling lengths of the two polarized states are defined as L_a and L_b, respectively, it's possible that by adjusting the configuration parameters, the coupling lengths of the two polarized states can meet the equation of $L_b=L_a/2$. Accordingly, when launching from one core, one polarized state in the input core can be completely coupled into the other core, while the other state is only coupled partly and will be coupled back to the input core. As a result, the two polarized states launching from the input core can be separated.

Fig.1 shows the cross section of a dual-core PCF. The background index of the fiber is set as $n = 1.45$ and the material dispersion is omitted for simplicity. The period of air-holes is Λ, and the normalized diameter of cladding air-holes is set as $d/\Lambda = 0.5$. There are three types of air-holes surrounding the cores named as A, B and C, whose diameters are d_1, d_2 and d_3, respectively. The structure is composed of a large core and a small one. The small core is realized by the omission of one air hole in the fiber. Two different sizes of air holes are used to introduce birefringence into the small core. The large core is composed of seven down-doped silica rods with diameter of d_4. The index difference between the down-doped rods and the pure silica is Δ. The large core is surrounded by air holes with diameter of d_3.

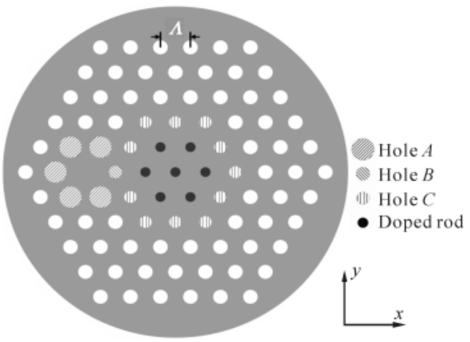

Fig.1 Cross-section of the proposed dual-core photonic crystal fiber

It should be noted that the index-matching between the fundamental modes of the two cores is difficult, owing to the large difference between the two core sizes. However, it can be realized for the fundamental mode (LP_{01}) of the small core PCF and the higher-order mode (LP_{02}) of the large core PCF. In coupled-mode theory, each core can be treated as an independent waveguide that is perturbed by the presence of fields propagating in the other core. We solve the modes of each core by a semi-vectorial beam propagation method (SV-BPM)[10,11]. Numerical results show that the decrease of d_1/Λ will lead to the increase of the effective index of the LP_{01} mode in the small core. But the slope of the curve is increased. The diameter of Hole C has similar influence on the effective index of the LP_{02} mode. It's also found that the variation of the index difference Δ only leads to the increase or decrease of the effective index for the large core, whereas the slope of the curve is kept unvaried. Therefore, the index-matching can be met for the x-polarized states of the two cores by tuning the diameters of air-holes surrounding the large core and small core, respectively, so that the slopes of the index curves in the two cores can match in a wide wavelength range. And then, the index curves of the small and large cores are met by tuning the refractive index of the doped rods in the large core. Finally, by fine-tuning the diameter of Hole B, the curves can be fitted better. Fig.2 shows the effective indices of the modes of the two cores, where the parameters are chosen as d_1/Λ=0.712, d_2/Λ=0.437, d_3/Λ=0.3, d_4/Λ = 0.42, and Δ = -0.003, respectively. In fact, the maximum index difference for the x-polarized state is as low as 4.76×10^{-5}, whereas the index difference for the y-polarized state is larger than 1.79×10^{-4} in the wavelength range shown in the figure.

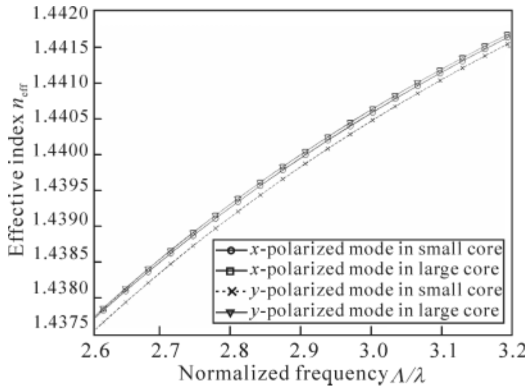

Fig.2 Effective index curves of the LP_{01} mode in small core PCF and the LP_{02} mode in large core PCF

The performance of the polarizer is calculated by applying SV-BPM. The wavelength of the incident light is set as 1.55 μm and the light is launched into the small core. Fig.3 illustrates the normalized power transferred along the fiber length when the period of the air-holes is set as Λ=4.6 μm. The coupling lengths of the x- and y-polarized states are 11.3 mm and 5.65 mm, respectively, corresponding to a coupling length ratio of L_x/L_y=2. Therefore, if the fiber length is set as 11.3 mm, the x-polarized state will be transferred to large core completely, whereas only the y-polarized light will be coupled back to the small core. Therefore, the y-polarized fundamental light can be emitted from the small core.

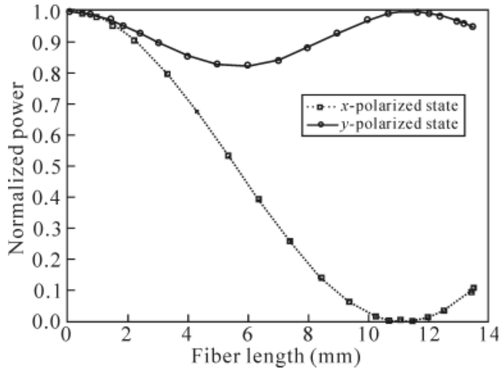

Fig.3 Normalized power transferred in the small core for the proposed fiber with Λ=4.6 μm

The extinction ratio, which is defined as the power ratio between the undesired and the desired polarized states in each output core, is -25 dB for small core at λ = 1.55 μm. As shown in Fig.4, the extinction ratio is below -20 dB for the wavelength ranging from 1510 nm to 1590 nm for the *y*-polarized state.

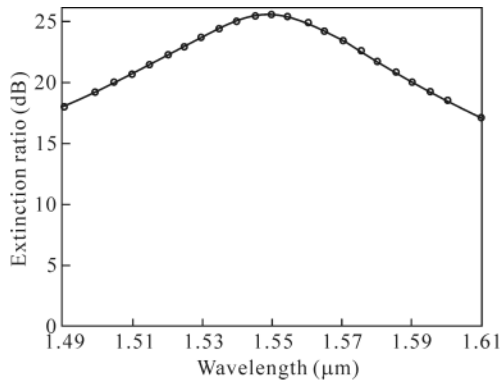

Fig.4 Extinction ratio of the fiber polarizer as a function of wavelength

In addition, Fig.5 also shows mode distribution of the *y*-polarized state in the small core. Owing to the fact that we do not require very high birefringence in the small core, the field still shows a regular profile, which ensures more efficient coupling with the conventional optical fiber.

A novel optical fiber polarizer based on an asymmetric dual-core PCF is proposed and the optical characteristics of the polarizer are investigated. We have employed the fact that the coupling length of the mismatched polarization state is shorter than that of the index-matched polarization state. As a result, a fiber optical polarizer with a short length of 11.3 mm, a broad operating bandwidth of 80 nm and the extinction ratio below -20 dB is obtained.

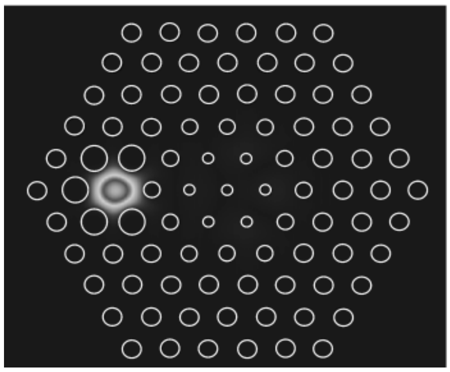

Fig.5 Electric field distribution of *y*-polarized state

References

[1] J. R. Folkenberg, M. D. Nielsen and C. Jakobsen, Opt. Lett. **30**, 1446 (2005).

[2] M. Y. Chen and Y. K. Zhang, Opt. Lett. **33**, 2542 (2008).

[3] M. Y. Chen, B. Sun and Y. K. Zhang, J. Lightwave Technol. **28**, 1443 (2010).

[4] L. Zhang and C. Yang, IEEE Photon. Technol. Lett. **16**, 1670 (2004).

[5] L. Zhang and C. Yang, Opt. Express **11**, 1015 (2003).

[6] K. Saitoh, Y. Sato and M. Koshiba, Opt. Express **12**, 3940 (2004).

[7] L. Rosa, F. Poli, M. Foroni, A. Cucinotta and S. Selleri, Opt. Lett. **31**, 441 (2006).

[8] M. Y. Chen, B. Sun, Y. K. Zhang and X. X. Fu, Applied Optics **49**, 3042 (2010).

[9] M. M. Ding, L. X. Song, H. Q. Yu and C. L. Zhou, Beijing: High Education Press, 2005.

[10] R. J. Yu, Y. Xiang, M. Y. Chen and J. M. Jia, Journal of Optoelectronics • Laser **15**, 775 (2004). (in Chinese)

[11] Y. Z. He and F. G. Shi, Opt. Commun. **225**, 151 (2003).