Characteristics of a polarization splitter constructed from two optical fibers with a circular hollow pit outside a core

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A new fiber-type polarization splitter is proposed. This polarization splitter is constructed from two optical fibers with a circular hollow pit outside a core. The characteristics of the device length, the extinction ratio, and the bandwidth in terms of the structural parameters for the polarization splitter are discussed.

Keywords : fiber, coupling, polarization splitter

1. Introduction

The fiber-type polarization splitter has been utilized as a constituent element of the coherent optical communication system and the optical sensor system. The polarization splitter is generally designed so as to realize the shorter device length, the smaller extinction ratio, and the wider bandwidth. Yokohama et al.⁽¹⁾ had reported that the device length could be short by inventing a configuration of the birefringent fibers (PANDA fibers) with complicated structures. The simple polarization splitters with two optical fibers configured on the same axis is also studied^{(2)~(4)}. We have reported characteristics of polarization splitter constructed from two optical fibers with a single core. The device length was 54.7cm and the bandwidth was 0.269nm⁽⁴⁾.

In this letter, we propose a new polarization splitter constructed from two optical fibers with a circular hollow pit outside a core (see Fig.1). The characteristics of the device length, the extinction ratio, and the bandwidth for the polarization splitters are investigated. The device length of 6.44cm, the extinction ratio of -29.7 dB, and the bandwidth of 2.26nm are attained.

2. Analysis

The cross section and coordinate system of the polarization splitter are shown in Fig.1. Let the z-axis be in the inward direction. The cross section of the polarization splitter is symmetric about the x-axis. The wave is assumed to propagate along the z-axis. The origins O_1 and O_2 are the centers of the core-1 of

Fig.1 The cross section of the polarization splitter

the fiber-1 and the core-2 of the fiber-2, respectively. The origins O_3 and O_4 are the centers of the pit-1 of the fiber-1 and the pit-2 of the fiber-2, respectively. Four cylindrical coordinate systems (r_1, θ_1, z) , (r_2, θ_2, z) , (r_3, θ_3, z) , (r_4, θ_4, z) are used for the complete modal expansions. The refractive indices of the core-1, core-2, and cladding are $n_1(\lambda)$, $n_2(\lambda)$, and $n_c(\lambda)$, respectively. The refractive indices of the pit-1 and the pit-2 are n_3 and n_4 , respectively.

Fig.2 is the configuration of the polarization splitter. When the power is excited at $z=0$, X-polarization which is linearly polarized wave polarizing along x-direction is derived from core-1 and Y-polarization which is linearly polarized wave polarizing along y-direction is derived from core-2.

In the polarization splitter with two cores, the HE_{11} mode in a single core fiber is split into the even modes [with the even mode propagation constants of $\beta_e^{(x)}$ and $\beta_e^{(y)}$, where X and Y express X-polarization and Y-polarization, respectively] and the odd modes [with the odd mode propagation constants of $\beta_o^{(x)}$ and $\beta_o^{(y)}$]. The only above four modes are studied as the guided modes.

In the following analyses, IPMM (Improved Point Matching Method)⁽⁵⁾ is taken as the numerical technique. The propagation constants can be computed from the eigenvalue equations obtained by imposing the boundary conditions ($r_1 = a_1$, $r_2 = a_2$, $r_3 = a_3$, $r_4 = a_4$) for the each core, each pit, and cladding. The relative errors of the propagation constants are kept all less than

Fig.2 The polarization splitter

Table 1 L versus a_3/a_1

a_3/a_1	1.0	2.0	3.0	4.0
$L(\text{cm})$	8.78	7.49	6.55	6.44

10^{-8} . The electromagnetic fields and the weight coefficients modes are computed by using the obtained propagation constants, and then the power in each core for each polarization is obtained from the electromagnetic fields and the weight coefficients modes⁽⁶⁾. The electromagnetic fields, the weight coefficients of the modes, and the power are computed on the x-axis because the cross section is symmetric about the x-axis. The power in each core is normalized such that X-polarization power and Y-polarization power excited core-1 at $z=0$ become unity.

The extinction ratios $R_1(z)$ and $R_2(z)$ at the propagation distance z are obtained from the following equations and let $R(z) \triangleq \max[R_1(z), R_2(z)]$ (max [u1, u2]: larger of u1 and u2).

fiber-1:

$$R_1(z) = 10 \log_{10} [P_1^{(Y)}(z)/P_1^{(X)}(z)] \quad (1)$$

fiber-2:

$$R_2(z) = 10 \log_{10} [P_2^{(X)}(z)/P_2^{(Y)}(z)] \quad (2)$$

$P_q^{(Y)}(z)$: Y-polarization power in the core- q ,

$P_q^{(X)}(z)$: X-polarization power in the core- q ,

$q=1,2$.

3. Results

The structures of the fiber-1 and the fiber-2 are assumed to be identical [$a_1 = a_2$, $a_3 = a_4$, $n_1(\lambda) = n_2(\lambda)$, $n_3 = n_4$]. The refractive index [$n(\lambda) \triangleq n_1(\lambda) = n_2(\lambda)$] of the core and the refractive index $n_c(\lambda)$ of the cladding are given by Ref. (4). Refractive indices of the pits are $n_3 = n_4 = 1$. The relative index difference $\Delta(\lambda)$ between the core and the cladding are defined by $\Delta(\lambda) \triangleq [n^2(\lambda) - n_c^2(\lambda)]/[2n^2(\lambda)]$. In the following numerical analysis, the radius of the core is $a_1 = a_2 = 3.3 \mu\text{m}$, the normalized core spacing is $d/a_1 = 2.0$, the operating wavelength is $\lambda = 1.55 \mu\text{m}$, and the relative index difference of the core is $\Delta(1.55) = 0.5\%$.

The propagation distance z at which $R(z)$ first becomes -20.0 dB is defined as the device length L . Table 1 shows the device length L against the radius ratio ($\triangleq a_3/a_1$) of the pit. The value of a_3/a_1 is selected as 1.0, 2.0, 3.0, and 4.0. From Table 1, it is found that the larger the value of a_3/a_1 , the smaller the value of L .

Fig.3 shows the extinction ratio $R(L)$ versus the wavelength λ for the same value of a_3/a_1 in Table 1. The following results are derived from Fig.3.

- 1) The $R(L)$ takes its minimum value of -29.7 dB at $\lambda = 1.55057 \mu\text{m}$ and $a_3/a_1 = 2.0$.
- 2) When a practical extinction ratio is assumed to be $R(L) = -15.0$ dB⁽⁷⁾, the bandwidth becomes the largest value of 2.26 nm for $a_3/a_1 = 2.0$.

4. Conclusion

In this letter, we proposed a new polarization splitter constructed from two optical fibers with a circular hollow pit out-

 Fig.3 The extinction ratio $R(L)$ versus λ

side a core. The characteristics of the device length and the bandwidth were discussed in terms of the radius ratio of the pit. As results, the minimum device length of 6.44 cm, the minimum extinction ratio of -29.7 dB, and the maximum bandwidth of 2.26 nm were attained. The device length could be 0.118 times smaller than that in Ref. (4), and the bandwidth could be 8.41 times larger than that in Ref. (4).

We will continually investigate polarization splitters for the more excellent characteristics.

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References

- (1) I. Yokohama, K. Okamoto, and J. Noda: "Analysis of fiber-optic polarizing beam splitters consisting of fused-taper couplers", IEEE J. Lightwave Technol., **LT-4**, 9, pp.1352-1359 (1986).
- (2) M. S. Yataki, D. N. Payne, and M. P. Varnham: "All-fiber polarising beamsplitter", Electron. Lett., **21**, 6, pp.249-251 (1985).
- (3) K. Morishita and K. Takashina: "Polarization properties of fused fiber couplers and polarizing beamsplitters", IEEE J. Lightwave Technol., **9**, 11, pp.1503-1507 (1991).
- (4) K. Kameda, S. Furukawa, and T. Hosono: "Characteristics of polarization splitter constructed from coupled two optical fibers", Trans. IECE Japan, **J80-C-I**, 11, pp.491-499 (1997), (in Japanese).
- (5) T. Hinata, H. Yoshikawa, H. Kuroiwa, and T. Hosono: "Analysis of polarization-maintaining optical fibers with circular pits outside a circular core", IECE Japan, **J68-C**, 11, pp.893-900 (1985), (in Japanese).
- (6) K. Kameda, S. Furukawa, T. Hinata, and T. Hosono: "Characteristics of polarization splitter constructed from two optical fibers with a circular hollow pit outside a core", OFSET2000, pp.219-222, Japan (2000).
- (7) Wu C. W. Cheng, T. L. Wu, and H. C. Chang: "A novel fabrication method for all-fiber weakly fused polarization beamsplitters", IEEE Photonics Technol. Lett., **7**, 7, pp.786-788 (1995).