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Single-polarization operation in suspended-core microstructured fibers

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ABSTRACT

We present the design and investigation of a single-polarization suspended-core fiber with an elliptical core consisting of crossed rectangular-shaped dielectric strips. By optimizing the fiber configuration parameters, single-polarization single-mode transmission with a bandwidth of 400 nm can be obtained. Also, the power fraction in air of the x-polarization fundamental mode is relatively high, which facilitates its applications in high precision sensors.

1. Introduction

Single-polarization single-mode (SPSM) fibers, which support only one polarization state within a particular wavelength range, can suppress both polarization mode coupling and polarization mode dispersion. SPSM fibers have extensive applications in various technologies such as fiber optic gyroscopes, high power fiber lasers, current sensors, and other polarization-sensitive components. There have been remarkable advances in SPSM fibers over the past decade, and various SPSM fibers have been proposed and investigated [1–9]. Photonics crystal fibers (PCFs) are an attractive type of fiber for flexibly achieving SPSM transmissions. However, most SPSM PCF designs are based on solid core fibers, and the power of the guided mode is mostly distributed in the material. In contrast, bandgap-guided hollow-core fibers (HCFs) can guide light in air, and this can be used to sense gas and liquid. Furthermore, better sensitivity can be obtained because there is low-loss guidance directly in the sample. To date, HCFs have not been widely adopted for use in practical applications, mainly because they tend to have few modes and it is difficult to control polarization coupling and polarization mode dispersion [7–9]. In polarization-sensitive sensing applications, such as high-precision interferometric sensors, it is necessary to use single-polarization single-mode fibers [10,11]. Additionally, to increase sensor sensitivity, a strong evanescence field is required.

The suspended-core PCF based on the index-guiding mechanism is another promising kind of fiber that can provide single-mode operation while maintaining a relatively larger fraction of the guided mode power in air [12]. This type of fiber is attractive for chemical, biological, and gas sensing applications because of its high evanescence field overlap factor [13,14]. Highly birefringent suspended-core fibers, suspended two-core fibers, and suspended multi-core fibers have been designed and investigated [15–18]. However, to the best of our knowledge, there are few reports on SPSM suspended-core fibers.

In this paper, an SPSM suspended-core fiber is proposed. In the center of the fiber, an elliptic fiber core is suspended. The size of this fiber core depends on the thickness of the strips and the tilt angle of the strips relative to the x-axis. By adjusting the fiber parameters, we show that one polarization mode can be effectively eliminated and that SPSM transmission can be achieved over a wide wavelength range.

2. Geometry of the fiber

A schematic of the SPSM suspended-core fiber is shown in Fig. 1. A rectangular-shaped dielectric strip is oriented at an angle θ to the x-axis, and the other strip is in a direction at an angle π-θ to the x-axis. The two strips have the same thickness and width, and the intersection of the two strips acts as the fiber core. The rest of these

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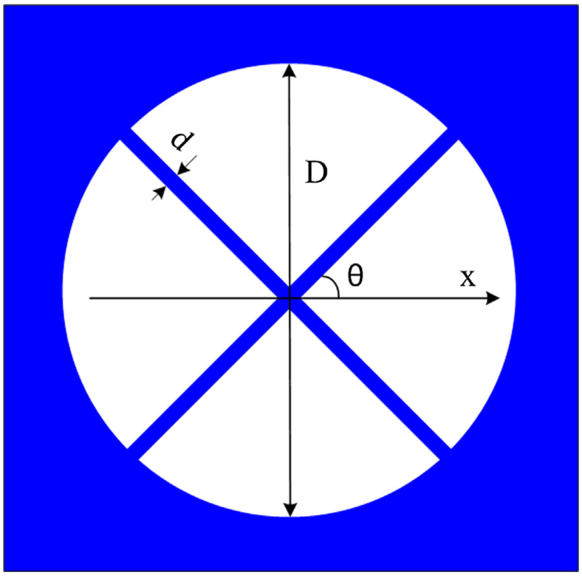

Fig. 1. Cross-section of the proposed fiber.

rectangular shaped strips and the four large air holes constitute the cladding of the fiber. The guiding mechanism of the proposed fiber is total internal reflection. The thickness and width of the dielectric strips are d and D, respectively. The refractive index of the dielectric material is 1.45, and material dispersion is ignored. When θ = 45°, a small circular solid core with radius of $d/2^{0.5}$ is suspended in the center of the fiber. As θ is reduced, an elliptical solid core forms with a semi-major axis of d/(2sin(θ)) and a semi-minor axis of d/(2cos(θ)), and this core leads to the highly birefringent characteristics of the optical waveguide.

The modal birefringence of the fiber is defined as

$$B = |n^x_{eff} - n^y_{eff}| \tag{1}$$

where $n^x{}_{eff}$ and $n^y{}_{eff}$ are the effective indexes of the x- and y-polarized modes, respectively, of the fiber.

The confinement loss of the fiber can be deduced from the imaginary part of the complex mode index by the following formulation [19]

$$\alpha_{con} = \frac{2\times 10^7}{\ln 10}\frac{2\pi}{\lambda} Im(n_{eff}) dB/m \tag{2}$$

where $Im(n_{eff})$ is the imaginary part of the effective index for the guided mode.

Power fractions of the guided mode for different regions of the fiber are defined as

$$\eta_x = \frac{P_x}{P_{total}} = \frac{\int_{A_x} S_z dA}{\int_{A_\infty} S_z dA} \tag{3}$$

where S_z is the z-component of the Poynting vector, and the subscript x represents two different regions within the fiber structure: air and solid material.

The system is numerically characterized using a commercially available finite element method (FEM) solver with a perfectly matched layer (COMSOL3.5a). The computational region is meshed into ~50000 elements.

The fiber structure parameters were chosen as follows: d = 400 nm, D = 16 μm, and θ = 30°. Fig. 2 gives the radial distribution of the electric field intensity along the dielectric strip at 1.55 μm for the x- and y-polarized fundamental modes. The top and bottom insets in Fig. 2 are the corresponding electric field distributions of the x- and y-polarized fundamental modes, respectively. The effective indexes of the x- and y-polarized fundamental modes are 1.238 and 1.203, respectively. Hence, the modal birefringence, B, can be as high as 0.035. The confinement losses for the x-and y-polarized fundamental modes are 4.33×10^{-3} dB/m and 21.91 dB/m, respectively. Considering that the material absorption losses for infrared light can be ignored, the loss of the y-polarized fundamental mode can be much higher than that of the x-polarized fundamental mode. As seen in Fig. 2, the y-polarized fundamental mode is more widely distributed along the radial direction compared to the x-polarized fundamental mode, which means that the y-polarized fundamental mode expands to the fiber cladding more easily and is harder to confine to the core. This is also why the y-polarized fundamental mode has higher confinement loss. Consequently, by adjusting the fiber structure parameters, one polarized mode can be effectively eliminated through a certain transmission distance, thus realizing single-polarization operation. In addition, the power fraction of the x-polarized mode in air can be as high as ~29.7%. This fiber—with its strong evanescent field—can be used for sensing applications that require high sensitivity.

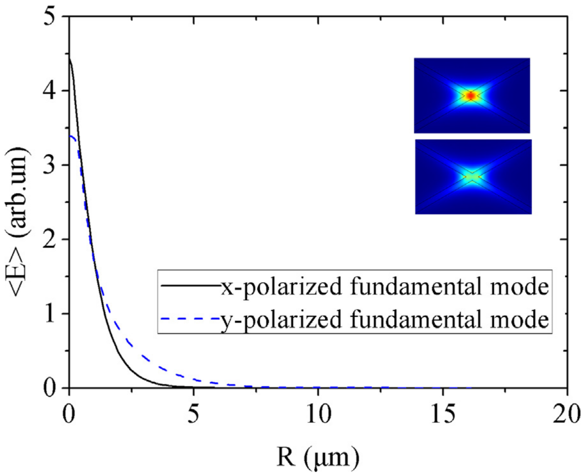

Fig. 2. Longitudinal component of the time-averaged electric field of the x- and y-polarized fundamental modes along the dielectric strip. The two insets are the electric field distributions of the x- (top) and y-polarized (bottom) fundamental modes.

3. Discussion

In the following, we will discuss the effects of the fiber structure parameters, such as the tilt angle of the strips relative to the x-axis and the thickness and the width of the dielectric strips, on the performance of the fiber birefringence and on loss of properties.

Fig. 3(a) shows the effective indexes of the two polarized modes as a function of θ at 1.55 μm with d = 400 nm and D = 16 μm. When θ = 45°, the fundamental mode of the fiber has two orthogonal degenerate polarizations with the same n_{eff}. As θ decreases, the effective index increases for the x-polarized fundamental mode and decreases for the y-polarized fundamental mode, which results in increasing birefringence as shown in Fig. 3(b). When θ is 20°, the birefringence of the fiber can be as high as 0.057. The confinement losses of the two polarized modes as a function of θ are presented in Fig. 3(c). When the value of θ is smaller, the difference between the confinement losses of the two polarized modes is larger, hence it becomes easier to obtain single polarization operation.

Fig. 4 shows the confinement losses of the two polarized modes as a function of D at 1.55 μm with d = 400 nm and θ = 30°. The confinement losses of the two polarized modes both increase with decreasing D values. The confinement loss of the y-polarized fundamental mode is always higher than that of the x-polarized fundamental mode. However, the value of D cannot be too small