Optics Communications 359 (2016) 448–454

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

A design for single-polarization single-mode photonic crystal fiber with rectangular lattice

Wan Zhang, Shu-guang Li*, Ya-jie Bao, Zhen-kai Fan, Guo-wen An

Key Laboratory of Metastable Materials Science and Technology, College of Science, Yanshan University, Qinhuangdao 066004, China

ARTICLE INFO

Article history:
Received 12 January 2015
Received in revised form
20 September 2015
Accepted 22 September 2015

Keywords:
Photonic crystal fiber
Single-polarization single-mode
The confinement loss

ABSTRACT

A design for single-polarization single-mode photonic crystal fiber with rectangular lattice is proposed in this paper. The proposed fiber is studied by the full vector finite element method with perfectly matched layers. The single-polarization single-mode operation region of the fiber is achieved in a certain wavelength range with low confinement loss include the wavelength of 1.55 μm. The loss of one polarization is 0.124 dB/km at the wavelength of 1.55 μm and the confinement loss of the other one polarization is very high which can not ensure the transmission in the fiber. The single-polarization single-mode photonic crystal fiber is desirable for some polarization-sensitive applications such as high-power fiber lasers, fiber optic gyroscopes, current sensors and optical coherent communication systems.

1. Introduction

Photonic crystal fibers (PCFs) present a wavelength-scale periodic microstructure running along their length. It has been intensively studied due to their unique properties which could be difficult to realize in conventional optical fibers because of the flexibility for the cross section design [1–5], such as endlessly single-mode guiding [6], controllable nonlinearity [7], flexible chromatic dispersion over a wide wavelength range [8], a large effective area [9] and high birefringence [10].

During the past decades, single-polarization single-mode (SPSM) fibers attract a lot of people's attention which guide only one polarization state of the fundamental mode. Its design principles can be summarized as two categories. The one is the use of the birefringence around the core which is called "deadline method" [11]. This can make the effective refractive index of a polarization state of the fundamental mode less than the effective refractive index of the cladding. Therefore, this polarization state model which does not meet the law of total internal reflection can not spread in the core. Meanwhile, the effective refractive index of the other polarization state is greater than the effective refractive index of the cladding, so this model which satisfies the law of total internal reflection can spread in the core. Highly birefringent PCFs have a potential in realizing SPSM fibers [12–14]. The potential of PCFs acting as SMSP fibers was first predicted by Steel et al. [15] when considering the polarization properties of elliptical-hole PCFs. The other one is called coupling method by using "resonant coupling theory" [16]. At a specific wavelength, when a polarization state model of the fundamental mode and cladding mode or high loss area mode meet the "transverse resonant coupling equations and conditions", the energy of the polarization state will shock attenuation between the core and the cladding and the loss of the polarization state will be significantly attenuated. However, another polarization state model is not satisfied the condition so that it can transport with low loss in the core. Then SPSM operation is obtained. In this paper, the "deadline method" is used to achieve SPSM fibers. So far, various SMSP fibers utilizing PCFs or HFs have been proposed or demonstrated [17,18]. SMSP fibers can eliminate both polarization mode coupling and polarization mode dispersion, which is desirable for some polarization-sensitive applications such as high-power fiber lasers, fiber optic gyroscopes, current sensors and optical coherent communication systems.

In this paper, we demonstrate a novel design for achieving single-polarization single-mode (SPSM) operation at 1.55 μm. The proposed PCF is based on a rectangular lattice PCF with two lines of three horizontal central air holes enlarged and two vertical smalled. By adjusting the structural parameters, SPSM operation is achieved in a certain wavelength range with low loss include the wavelength of 1.55 μm. We study the proposed fiber with the full vector finite element method(FV-FEM) [19,20] with perfectly matched layers(PMLs) [21].

2. Numerical method and design

PCF is a special optical waveguide in which the light transmits by the theory of electromagnetic waves transmission. Maxwell's equations are the basis of numerical calculation. We use the full-

* Corresponding author.
E-mail address: shuguangli@ysu.edu.cn (S.-g. Li).

http://dx.doi.org/10.1016/j.optcom.2015.09.079
0030-4018/

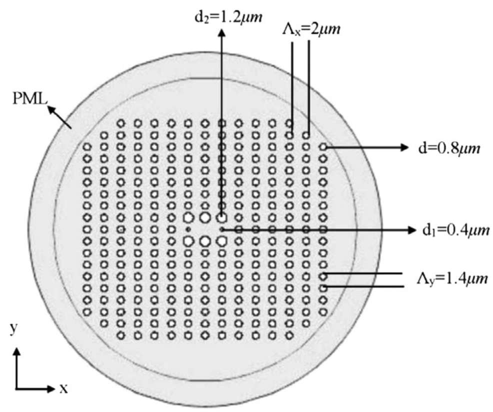

Fig. 1. Cross section of the proposed SPSM PCF.

vector finite element method (FEM) with the perfect matched layer (PML) boundary conditions to analyze the effective index and the confinement loss of the proposed SPSM PCF. The effective index n_{eff} of the mode is determined by

$$n_{eff} = \mathrm{Re}(\beta/k_0)$$

where k_0 is the free space wave number, and β is the propagation constant obtained by solving the eigenvalue equation. From the imaginary part of n_{eff} the confinement loss L for the corresponding mode is derived,

$$L = 8.686 \times \frac{2\pi}{\lambda}\mathrm{Im}(n_{eff}) \times 10^{-3}$$

where n_{eff} is the effective refractive index of the core, and the units of the confinement loss and the wavelength λ are dB/km and meter, respectively.

A novel design for achieving single-polarization single-mode (SPSM) operation at 1.55 μm is demonstrated. The "deadline method" is used to comply the fiber. The proposed PCF is based on a rectangular lattice which has different hole spacings in the horizontal direction and the vertical direction to obtain birefringence. Then the six air holes up and down around the core are enlarged and two left and right around the core are smalled as shown in Fig. 1. The changing of the air holes around the core makes a greater birefringence.

The diameter of the air holes in the cladding is $d=0.8$ μm. The diameter of six air holes enlarged is $d_2=1.2$ μm and the diameter of the two air holes smalled is $d_1=0.4$ μm. The pitch of two adjacent air holes in the horizontal and vertical direction are $\Lambda_x=2$ μm and $\Lambda_y=1.4$ μm, respectively.

Pure silica has been adopted as the background material whose chromatic dispersion was calculated by the Sellmeier equation; thus the material dispersion of the fiber was taken into account.

3. Simulation results and discussion

Fig. 2 shows the distribution of fundamental mode field and the fundamental space-filling mode (FSM) [22] field in x-polarized and y-polarized direction. As we know, endlessly single mode (ESM)

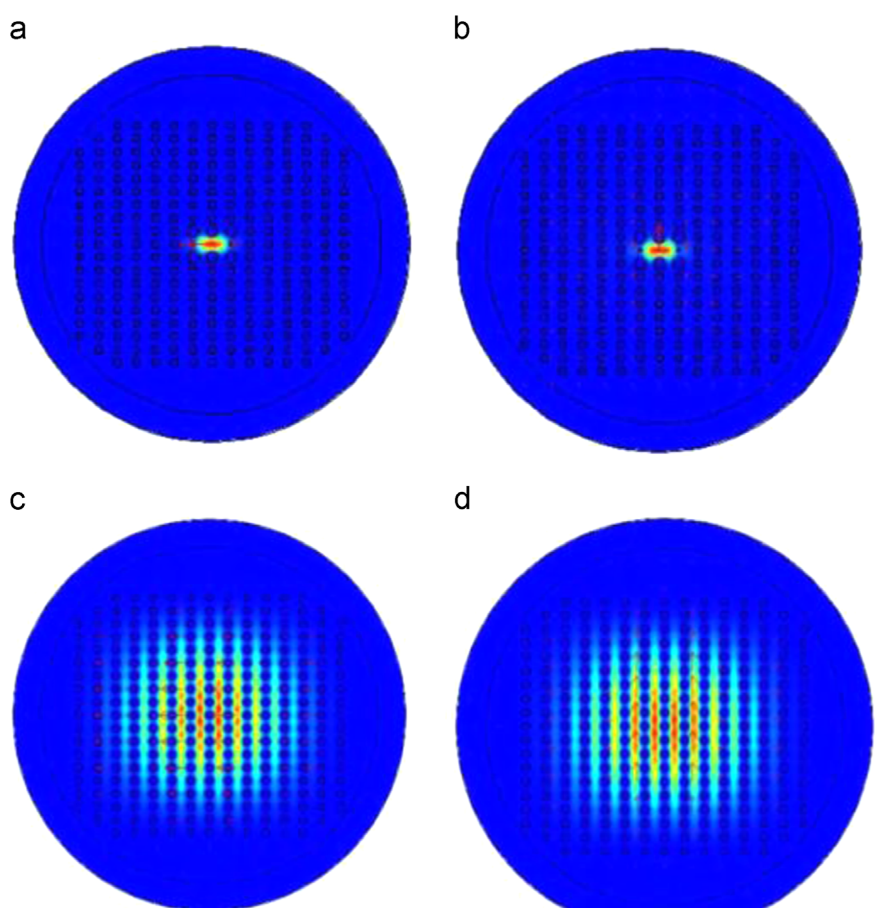

Fig. 2. The distribution of fundamental mode field and the fundamental space-filling mode field. (a) x-polarized mode of fundamental mode (b) y-polarized mode fundamental mode (c) x-polarized fundamental space-filling mode (d) y-polarized fundamental space-filling mode.