Optical Materials 73 (2017) 638–641

Contents lists available at ScienceDirect

Optical Materials

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

Design of a novel photonic crystal fiber filter based on gold-coated and elliptical air holes

Yunyan Zhao*, Shuguang Li, Qiang Liu, Xinyu Wang

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

ARTICLE INFO

Article history:
Received 21 May 2017
Received in revised form
17 August 2017
Accepted 18 August 2017

Keywords:
Photonic crystal fiber
Polarization filter
Surface plasmon resonance
Gold-coated

ABSTRACT

In recent years, photonic crystal fibers have played an important role in the field of optical communications, and the addition of metal materials to photonic crystal fibers have offered new ways to improve the transmission characteristics of optical fibers. We design a new type of gold-coated photonic crystal filter, which utilizes the surface plasmon resonance effect, and study it by using the finite element method. In this paper, we optimise the structure parameters and analyze the numerical results. The numerical results show that the thickness of metal layer and the air holes near the fiber core strongly affect the performance of the polarization filter. For the operating wavelength of 1550 nm, the loss in the y-polarization direction can be as high as 906.9 dB/cm, which is much larger than the x-polarization direction. When the fiber length is longer than 100 μm, the crosstalk in the wavelength range from 1.4 μm to 1.9 μm is greater than 20 dB. The proposed optical fiber can find application as an optical fiber polarization filter.

1. Introduction

As a new communication technology, compared with the traditional optical fiber, photonic crystal fibers (PCFs) [1–3] have many advantages. As time passed, the researchers found that some materials can be applied to optical fiber communication technology, such as liquids [4], liquid crystals [5], oil [6], or metals [7]. The addition of a certain amount of material to the fiber affects its transmission characteristics [8–11]. This attracted the interest of many researchers. More recently, gold-filled and gold-coated photonic crystal fibers have been considered. The results show that the use of metal materials can produce photonic crystal fibers with better transmission performance.

After adding the metal material, the surface of the metal will form the surface plasmon polaritons (SPP). In addition, when phase matching conditions between core mode and SPP mode are met, coupling resonance phenomenon will occur at a certain wavelength. Nowadays, many researchers have done a lot of novel designs on this basis. Nagasaki et al. [12] have described that the surface plasmon resonance effect can produce loss peak wavelengths. On the basis of the plasma resonance effect, Xue and Li [13] designed a photonic crystal fiber with selective addition of gold and filled liquid whose loss in the y polarization direction reached 508 dB/cm. Wang proposed a quadrilateral coated metallic photonic crystal fiber which can achieve a resonance strength of 720 dB/cm in the y-polarized direction [14]. The results show that the gold-coated photonic crystal fiber has better filtering effect than the gold-filled photonic crystal fiber.

In this paper, we have designed a new type of photonic crystal fiber with elliptical air holes and selectively plated gold to the air holes. Simul-ation results show that, compared with [12–14], the PCF has better polari-zation filter characteristics and higher cross talk (CT)at the communication wavelength. At the same time, we also compared the characteristics of the PCF between gold-coated and gold-filled.

2. Structure and theroretical principle

The cross section of the PCF polarized filter with elliptical air holes is shown in Fig. 1. Here, the core is formed by removing an air hole in the center. It has four large air holes and two elliptical air holes around it. At the same time, the whole structure is formed by rotating the quadrilateral by 45°. In order to form the surface plasmon effect, we have coated gold on the upper and lower air holes of the core, respectively. As shown in Fig. 1, d_1 and Δ denote the diameter and lattice spacing of the clad air holes, respectively.

* Corresponding author.
E-mail address: 15032385268@163.com (Y. Zhao).

http://dx.doi.org/10.1016/j.optmat.2017.08.029
0925-3467/

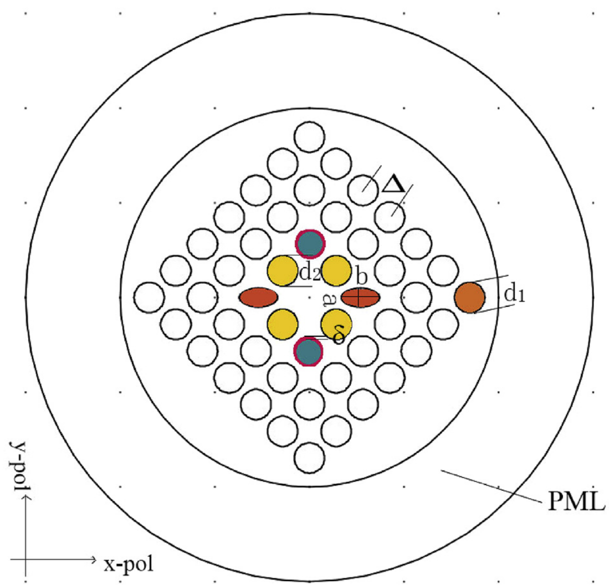

Fig. 1. Cross section of the proposed photonic crystal fiber filter.

In addition, the diameter of the four large holes is d_2, where a and b are the minor axis length and the major axis length of the elliptical hole, respectively.

For this structure, the parameters d_1, d_2, a and b are fixed to 0.8 μm, 0.8 μm, 0.5 μm and 1.0 μm, respectively. The lattice pitch is $\Delta = 2$ μm and the thickness of the gold layer δ is fixed to 20 nm. We use pure silica as the background material. Its chromatic dispersion is calculated by the Sellmeier equation [15]. The refractive index of air is 1. The permittivity of the gold is calculated by the Drude-Lorentz model [16]:

$$\varepsilon_m = \varepsilon_\infty - \frac{\omega_D^2}{\omega(\omega - j\lambda D)} - \frac{\Delta\varepsilon \cdot \Omega_L^2}{\left(\omega^2 - \Omega_L^2\right) - j\Gamma_L\omega}$$

where ε_∞ is the high-frequency permittivity, $\varepsilon_\infty = 5.9673$; $\Delta\varepsilon = 1.09$, Ω_L and Γ_L are the frequency and the spectral width of the Lorentz oscillator, respectively. ω is the angular frequency of guided light, while ω_D and γ_D represent the plasma freq-uency and damping frequency. Here, $\omega_D/2\pi = 2113.6$ TH Z; $\gamma_D/2\pi = 15.92$ THZ; $\Omega_L/2\pi = 650.07$ THZ; $\Gamma_L/2\pi = 104.86$ THZ. As an important parameter of polarizati-on filters, the mode loss of the fiber can be expressed as

$$L = 8.686 \times \frac{2\pi}{\lambda} \mathrm{Im}(neff) \times 10^4$$

There are two important parameters in the above equation: λ and Im (neff), which represent the wavelength of the incident light and the imaginary part of the effective refractive index of the fiber core [17], and the units correspond to microns and dB/cm, respectively.

In the whole process of simulation using the finite element method, we apply the perfectly matched layer (PML) and the scattering boundary conditions (see Fig. 2). When the phase matching condition is reached, the core mode can be strongly coupled with the SPP mode.

3. Numerical results and analysis

Fig. 3 shows the fiber core mode and the surface plasmon polaritons (SPP) mode field distribution. Since we selectively plated the two air holes with gold film, the surface plasmon resonance effect was produced. In this way, the two modes mentioned above will be strongly coupled at a certain wavelength, and there will be greater energy loss in one of the polarization directions of this wavelength, so that it can be used as a polarization filter.

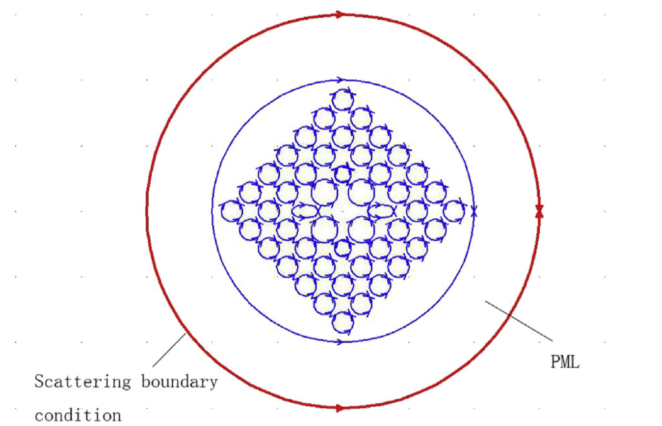

Fig. 2. PML and scattering boundary conditions.

When the structural parameters of the fiber are optimized, the peak value of the loss will appear in a certain direction of polarization due to the asymmetry of the structure, so as to achieve a good polarization filtering effect at this wavelength. Fig. 4 shows the loss dispersion profile for the optimized structural configuration.

At this time, d1, d_2, a and b are fixed at 0.8 μm, 0.8 μm, 0.5 μm and 1.0 μm and the thickness of the gold layer is fixed at 20 nm. It can be clearly seen from the figure that the core mode and the SPP mode of the Y-direction of the 1550 nm wavelength are strongly coupled so that the peak of the loss is much larger than that in the x-direction, and the fiber has a good polarization filtering effect at 1550 nm.

Another important parameter of the photonic crystal fiber filter is crosstalk (CT), which can represent the filtering effect of the filter, and it can be defined as [18]

$$CT = 20\lg\{\exp[(\alpha 2 - \alpha 1)L]\}$$

where $\alpha 1$ and $\alpha 2$ represent the loss in the X and Y directions, whereas L represents the fiber length. Fig. 5 shows the relationship between crosstalk and fiber length. As can be seen from the figure, with the increase in wavelength, CT also showed a certain change trend. When the length of the fiber exceeds 100 μm, in the 1.4–1.9 μm wavelength range, CT are more than 20 dB, which means that the fiber has a good filtering effect and can be used to make the filter.

As we know, when the structure of the optical fiber changes, some of its transmission characteristics will change accordingly. Therefore, if we analyze the variation of the influence of parameters on the transmission characteristics, we can have some guiding significance for the manufacture of optical fiber. So we have a simple analysis on some structural parameters, which may have some impact on the transmission characteristics of this fiber. In this paper, we focus on these two parameters: air holes diameter, gold film thickness and the size of the elliptical air hole.

Next, we discuss the effect of the four orifices surrounding the core on the fiber filter effect. As shown in Fig. 6, in this paper, when the other parameters remain constant, we make the gradient of d_2 from 0.6 μm to 1.1 μm. It can be seen in this band that the loss formant has red shift phenomenon in the y-polarized direction,