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Plasma dual-wavelength single polarizing filter with gold film and liquid-filled air hole based on photonic crystal fiber

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ABSTRACT

A square structure of dual communication band single polarizing plasma photonic crystal fiber filter is presented in this paper. The resonance point can be adjusted to the communication band by optimizing the parameters of fiber structure. High birefringence can be produced by changing the refractive index of the filled liquid, the thickness of the metal film, and the diameter of the air holes near the core. Numerical simulation results demonstrate that the resonance strength of *x*- and *y*-polarized direction can simultaneously reach 781.87 and 463.04 dB cm^{-1} at the communication wavelength of 1.31 and 1.55 μm. By filling liquid analyte the confinement loss of *x*- and *y*-polarized direction can simultaneously reach 804.71 and 451.69 dB cm^{-1} at the wavelength of 1.31 and 1.55 μm. Furthermore, when the fiber length of *L* is equal to 700 μm, the peak value of the crosstalk can reach 474.63 and −243.61 dB at the same time at the wavelength of 1.31 and 1.55 μm, and when the length of the fiber *L* is 400 μm, the bandwidths of the crosstalk better than 20 dB and less than −20 dB are about 160 and 220 nm, respectively. These features make it an ideal candidate for the design of a dual band polarization filter device.

1. Introduction

Because of the excellent performance of optical fiber and the development of manufacturing technology, it is widely used in sensing detection of signals [1,2]. Photonic crystal fiber (PCF), as a new type of optical waveguide device, has aroused more widespread concern due to its unique characteristics and advantages, such as endless single-mode transmission [3], controllable dispersion [4], flexible non-linearity [5], controllable birefringence [6] and large mode area [7]. PCF is divided into two types, namely, index-guided (IG) fiber [8] and photonic band gap (PBG) fiber [9]. Among them, IG PCF guides light through the total internal reflection between the high refractive index core and the low refractive index cladding, while PBG PCF directs light in the core region of low refractive index. In this paper, IG PCF is used. With the improvement of manufacturing technology, photonic crystal fibers, such as oval [10], rhombic [11], hexagonal [12], octagonal [13], spiral [14], mixed shape [15] and other different shapes are fabricated to improve their performance. PCF can be injected with oil [16], liquid [17], gas [18], polymer [19], metal [20] and other materials into the air holes of the cladding, so as to obtain new properties. In fact, selective filling is a relatively difficult task in industry, but some scholars have been able to implement it through special techniques. In 2004, Huang et al. achieved the selective filling of microstructured optical fiber (MOF) air holes by applying pressure on a syringe pump and a multistep injection-cure-cleave process [21]. In 2007, Zhang et al.

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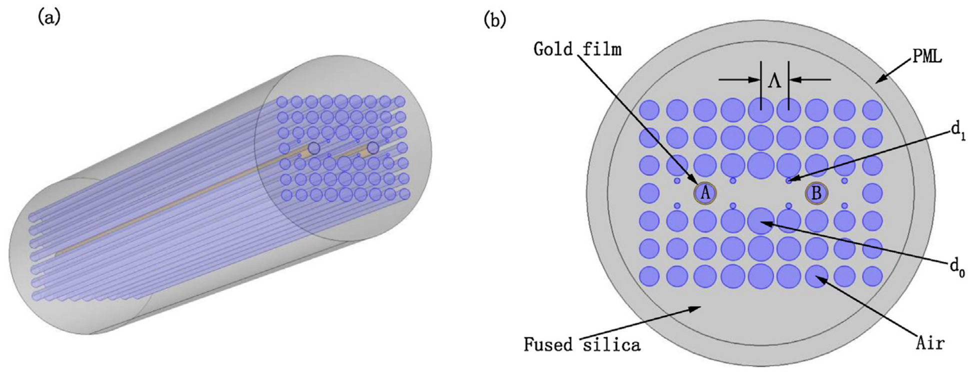

Fig. 1. Three-dimensional schematic of the PCF (a) and two-dimensional cross section of the PCF (b). (For interpretation of the references to color in this figure citation, the reader is referred to the web version of this article.)

used selective metal coating technology to successfully fill metal silver into the microstructure optical fiber air hole coating [22]. In 2011, Lee et al. achieved selective filling by splicing an intermediate capillary between the PCF and gold capillary [23]. In recent years, the study of the polarization characteristics of PCF has been explored. In 2014, An et al. presented a polarization filter of gold-filled photonic crystal fiber with regular triangular and rectangular lattices [24]. The resonance strength in y-polarization mode is 407 dB cm^{-1} at the communication wavelength of 1550 nm when the diameter of the gold wire is 0.6 μm. In 2015, Chen et al. reported a surface plasmon induced polarization filter based on Au wires and liquid crystal infiltrated photonic crystal fibers [25]. The confinement loss is 446 dB cm^{-1} in y-polarized direction at the communication wavelength of 1550 nm. In 2016, Hao et al. reported a photonic crystal fiber polarization filter with round lattice based on surface plasmon resonance [26]. The resonance strength is 364.8 dB cm^{-1} in y-polarized direction at the communication wavelength of 1550 nm, and when the fiber length is 800 μm, the peak value of the crosstalk can reach 231.8 dB. However, the resonant peaks of the x- and y-polarization modes are not completely separated. In 2017, Feng et al. reported a polarization filter based on photonic crystal fiber with a big gold-coated air hole [27]. The loss of the y-polarization is 58,456.7 dB m^{-1} at the communication wavelength of 1550 nm, and when the length of the fiber is 300 μm, the extinction ratio is 152.3 dB. But as far as we know, most PCF-based polarization filters can only work in a single communication band (1310 or 1550 nm), and it is still rare to realize biorthogonal polarizing mode filter at two communication bands simultaneously.

In this paper, we design a square structure of dual communication band single polarizing plasma photonic crystal fiber filter. The finite element method is used to calculate and analyze the performance characteristics of the PCF polarization filter. Numerous simulation results show that the symmetrical structure of the optical fiber can be destroyed by changing the refractive index of the filled liquid, the thickness of the metal film and the diameter of the air hole near the core, and then the intensity of the formant can be improved and the location of the resonant wavelength can be adjusted. The polarization filter can filter simultaneously at the communication wavelength of 1.31 and 1.55 μm by regulating the structure parameters of PCF. The resonance strength can simultaneously reach 781.87 and 463.04 dB cm^{-1} in x- and y-polarized direction at the communication wavelength of 1.31 and 1.55 μm respectively. After filling liquid into air holes, the resonance strength can reach 804.71 and 451.69 dB cm^{-1} at the same time in x- and y-polarized direction at the communication wavelength of 1.31 and 1.55 μm respectively. The design of dual-band polarization filter is very useful for the integration of communication devices in the field of optical communication.

2. Structure and theoretical model

Fig. 1(a) shows a three-dimensional schematic of the presented polarization filter based on gold coated air holes, and Fig. 1(b) shows its two-dimensional cross-section. The PCF consists of four layers of air holes in x-polarization direction and three layers of air holes in y-polarization direction, with the air holes arranged in a square lattice. The pitch between two adjacent air holes is labeled by Λ = 2.0 μm. The birefringence of the PCF is increased by gradually reducing the diameters of air holes from inside to outside in the x-polarized direction, and their diameters are 1.8, 1.7, 1.6, 1.5 and 1.4 μm, respectively. The two big air holes near the core in the vertical direction are helpful for producing high birefringence, and their diameters are d_0. The yellow parts of the air holes A and B are coated with metal Au, and the diameter of the eight smallest air holes in horizontal direction is d_1 = 0.6 μm, which can cause asymmetry factors.

The background material of PCF is fused silica, whose material dispersion can be obtained by the Sellmeier equation [28]. The material dispersion of gold can be learned through the Drude–Lorentz model [29], and the mode confinement loss in x and y polarization direction can be defined as:

$$\alpha = 8.686 \times \frac{2\pi}{\lambda} \mathrm{Im}(n_{\mathrm{eff}}) \times 10^4 \quad (1)$$