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Broadband core shift photonic crystal fiber polarization filter at 1.55 μm based on surface plasmon resonance

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ABSTRACT

A broadband core shift photonic crystal fiber (PCF) polarization filter based on surface plasmon resonance is proposed in this paper. The fiber is consisted of an asymmetric hexagonal lattice of holes in which a small air hole is coated with gold film and another one large air hole destroyed the structure around the core. The loss of y-polarized core mode is 2232.61 dB/cm at the communication wavelength of 1.55 μm, however, the loss of x-polarized core mode is very weak. When the PCF length is 300 μm, the bandwidth of exceeding 420 nm with extinction ratio better than −20 dB is achieved. To our best knowledge, the bandwidth is the widest. As a consequence, this special fiber filter has a wider range of applications.

1. Introduction

In recent years, the role of plasmonics is more and more obvious in the field of optics. The free electrons exist on the surface of plasmonic materials such as silver, gold. . . . . .etc. When light wave travels to the interface between the medium and the metal, it forms a near field electromagnetic wave by coupling with the free electrons of the collective oscillation. Thus, energy absorption induces surface plasmon resonance [1,2]. This phenomenon is widely used in communication transmission field. Many PCF devices based on surface plasmon resonance have been applied, including polarization filter [3], polarization splitter [4], optical switch [5], various types of sensors [6–8]. The applications of these fiber optic devices have brought great convenience to our life.

In order to use the phenomenon of surface plasmon resonance in PCFs, the researchers selectively coated or filled the metal in the air holes of the PCF to achieve new characteristics. Liu et al. [9] introduced a PCF polarization filter based on air holes selectively coated with a nanoscale gold film, which can be used for single wavelength polarization filtering and wide wavelength polarization filtering as long as the corresponding structural parameters are changed. Yang et al. [10] designed a high-birefringence PCF polarization filter, based on the fact that two air holes are coated with nanoscale silver film, so that the loss of x- and y-polarized mode is obviously separated. Lee et al. [11] designed and researched a high birefringence PCF filled with gold wire, and then, highly polarization and wavelength dependent transmission is observed. Luan et al. [12] proposed a nanoscale silver wires filled PCF, considering the temperature sensor of surface plasmon resonance principles, numerical results show that temperature sensitivity of up to 4 nm/k can be achieved. Tyagi et al. [13] introduced a PCF sensor based on air hole selectively filled with pure Ge wire, and the Ge wire is close to the PCF core position, causing strongly

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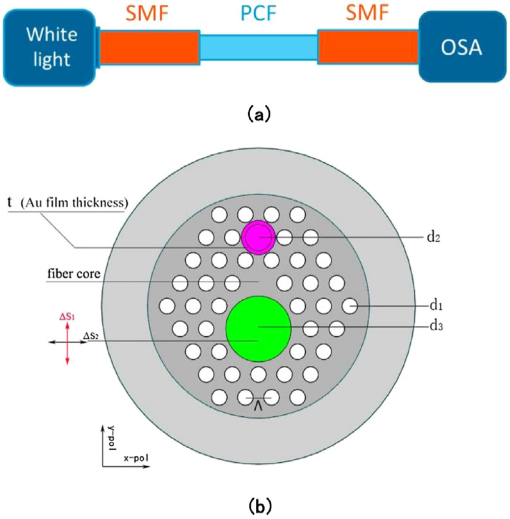

Fig. 1. Schematic diagram of PCF polarization filtering device (a) and the cross section of the designed PCF (b) (For interpretation of the references to colour in text, the reader is referred to the web version of this article).

polarization dependent transmission losses. The surface plasmon resonance phenomenon based on the coated metal film or filled metal wire in air holes of a PCF has become a hot research topic in recent years.

In this paper, we propose a broadband core shift PCF filter based on the selectively coated with gold film in the air hole of PCF. The PCF are calculated by the finite element method (FEM) [14]. The numerical simulation results show that the peak loss of y-polarized core mode is as high as 2332.61 dB/cm, while the peak loss in x-polarized mode is 11.19 dB/cm at the resonance wavelength of 1550 nm. Beyond that, we can flexibly adjust the resonant wavelength in the range of 1270 nm–1750 nm by altering the thickness of the gold film. Additionally, we can also change the size of large air hole (d_3) so that the resonant wavelength will change in the 1510 nm–1700 nm range. We also analyzed the influence of the large air hole moving up, down, left and right on the characteristics of PCFs, it is shown that the structure of our design is very stable. When the PCF length is about 300 μm, the extinction ratio is better than −20 dB and the bandwidth is above 420 nm. Therefore, our design of PCF filter has more obvious advantages and will have wide applications.

2. The structure and basic theory

Fig. 1(a) shows the schematic diagram of a polarization filtering system. In this system, white light as a light source, provide stable and continuous broadband lighting. We connect the PCF with two single-mode fibers (SMFs), the single-mode optical fiber (SMF) can be considered as a bridge between white light and spectrum analyzer (OSA), as well as PCF. Fig. 1(b) is a schematic diagram of the PCF cross section. The background material is pure silica, whose dispersion relation is achieved by the Sellmeier equation [15]. The white air holes in the cladding have a diameter of $d_1 = 1.2$ μm. The pitch of two adjacent air holes is $\wedge = 2$ μm. The purple air hole of d_2 is coated with gold film, and the thickness of gold film is expressed by t. The diameter of the green air hole is represented by d_3, where the large air hole (d_3) up and down translation parameters are represented by $\triangle S_1$, the left and right translation parameters are represented by $\triangle S_2$. Moreover, the core of our proposed PCF is off center.

The dielectric constant of gold is calculated by Drude-Lorentz model [16], which can be represented as

$$\varepsilon_m = \varepsilon_\infty - \frac{\omega_D^2}{\omega(\omega + j\gamma_D)} - \frac{\Delta\varepsilon \cdot \Omega_L^2}{\left(\omega^2 - \Omega_L^2\right) - j\Gamma_L\omega} \tag{1}$$

Where ε_∞ is the permittivity in the high frequency, $\varepsilon = 5.9673$; $\Delta\varepsilon = 1.09$ can is interpreted as a weighting factor, ω_D and γ_D represent the plasma frequency and damping frequency, $\omega_D/2\pi = 2113.6$ THZ, $\gamma_D/2\pi = 15.92$ THZ, ω is the angular frequency of transmitting light, Ω_L and Γ_L are the frequency and the spectral width of the Lorentz oscillator, $\Omega_L/2\pi = 650.07$ THZ; $\Gamma_L/2\pi = 104.86$ THZ.

The confinement losses of the x-polarized and y-polarized core modes can be calculated by:

$$\alpha(x, y) = 8.686 \times \frac{2\pi}{\lambda} Im(n_{eff}) \times 10^4 \tag{2}$$

Where the loss unit is dB/cm and the wavelength unit is μm, λ represents the wavelength of light and $Im\left(n_{eff}\right)$ represents the imaginary part of effective refractive index of the core.