Optik 160 (2018) 333–339

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Silver layer thickness insensitive index sensor based on hollow core photonic crystal fiber

Cheng Zhou*, Hai-kun Zhang, Peng Song, Jing Wang, Cun-guang Zhu, Peng-peng Wang

School of Physics and Technology, University of Jinan, Jinan, 250022, China

ARTICLE INFO

Article history:
Received 28 September 2017
Received in revised form 24 January 2018
Accepted 26 January 2018

Keywords:
Surface plasmons
Photonic crystal fiber
Fiber optics sensor

ABSTRACT

We propose a silver layer thickness insensitive index sensor based on silver coated on the inner wall of the HC-PCF. Under the boundary condition of anisotropic perfectly matched layer (PML), a full-vector finite element method (FEM) is used to calculate the fiber model. Numerical results indicate that the excitation of the plasmon mode is sensitive to the change of the refractive index of the adjacent analyte. The confinement loss of the core guided mode increases when both the refractive index of the analyte and the thickness of the silver film do. The maximum spectral sensitivity of the sensor can be 7330 nm/RIU. Furthermore, the spectral sensitivity of the sensor doesn't approximately change when the thickness of the silver film increases.

1. Introduction

Hollow-core photonic crystal fibers (HC-PCF), with extremely small sample volumes and low transmission losses in the visible and infrared regions, have been proposed for measuring micro-stain, temperature, gas and high refractive index surface plasmon resonance(SPR) micro-strain sensing [1], gas sensing [2], temperature sensing [3], high refractive index surface plasmon resonance(SPR) sensing [4,5], and so on. In 2013, Liu et al. [5] has reported experimentally a new kind of SPR sensor based on silver-coated hollow fiber structure filled liquids with high refractive index ranging from 1.494 to 1.697, and obtained sensitivity ranging from 1189 to 4356 nm/RIU. In 2015, P. Chen et al. [6] has reported experimentally a new kind of SPR sensor based on silver-coated hollow fiber structure filled liquids with high refractive index ranging from 1.4328 to 1.5102, and obtained sensitivity −2063 nm/RIU. The sensitivity of the above sensors is obviously changed with the thickness of the silver layer. However, it is difficult to optimize the sensitivity since the silver layer thickness is hard to be controlled when the silver film is coated on the inner wall of hollow-core fibers.

In order to overcome above the problem, we propose a silver layer thickness insensitive index sensor based on silver coated on the inner wall of HC-PCF. Under the boundary condition of anisotropic perfectly matched layer (PML), a full-vector finite element method (FEM) is used to calculate the fiber model. The effective refractive index of the mode field is obtained finally. The confinement loss of the core guided mode via the refractive index of the analyte and the thickness of the silver film is discussed in detail, for the HC-PCF sensor. Furthermore, we have also studied the sensing properties of the HC-PCF sensor in detail. Numerical results indicate that the excitation of the plasmon mode is sensitive to the change of the refractive index of the adjacent analyte. The maximum spectral sensitivity of the sensor can be about 7330 nm/RIU with 50 nm of silver

* Corresponding author.
E-mail address: cczhoucheng@sina.com (C. Zhou).

https://doi.org/10.1016/j.ijleo.2018.01.095
0030-4026/

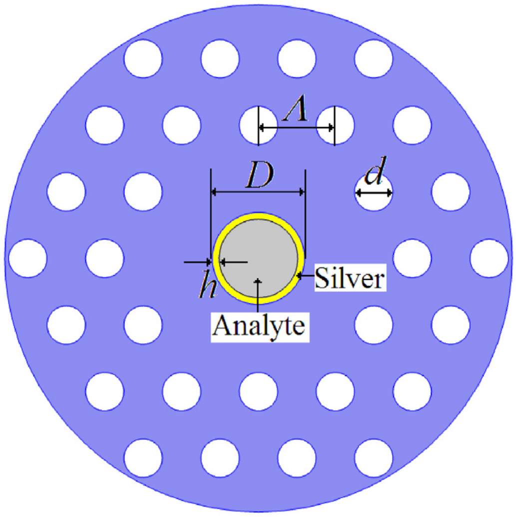

Fig. 1. Schematics of the SPR sensor based on the hollow core PCF.

film thickness and 1.41 of the refractive index of the analyte *n*. Its resolution can reach 1.4×10^{-5} RIU if it is typically a safe assumption that a 0.1 nm change in the position of a resonance peak can be detected reliably. The result is comparable to 4356 nm/RIU for high refractive index analyte reported by Liu et al. [5] and 2063 nm/RIU for high refractive index analyte reported by Chen et al. [6]. And it is important that the spectral sensitivity of the HC-PCF sensor is insensitive to the change of thickness of silver film *h*.

2. Design of geometrical structure

Transversal configuration of a HC-PCF sensor is shown as Fig. 1, which is made of three layers of air holes with a diameter *d* and a pitch Λ arranged in a hexagonal way and opened in a lossless quart glass optical fiber. The cores are formed by omitting corresponding air holes in the center and third layer, which are substituted by a large hole with a diameter *D*. A thin silver layer with a thickness *h* is coated on the inner surface of the large hole by an improved liquid phase deposition method [6]. Then, the liquid analyte was injected into the large hole with the thin silver layer by a peristaltic pump. The background material is silicon dioxide, and its material dispersion is already being considered using the Sellmeier equation [7]. The whole diameter of the solid core is about 40 μm.

In our simulation, the light transmitted through the liquid filled hollow core is absorbed by the analyte. However, the absorption coefficient of the analyte is about a constant in the range of the wavelength 500 nm–880 nm. And the intensity of the transmission light will whole decreases when the absorption of the analyte is counted. So, the influence of the spectral peak wavelength is negligible for the total transmission spectra of the sensor. Then, we only take into account of the confinement loss from the surface plasmon resonance.

In order to obtain field distribution and effective index of mode, we used numerical finite element method (FEM) [8,9] with triangular elements. The fundamental mode LP_{01} field distribution is given in Fig. 2(a), when operational wavelength λ is 748 nm. And diameters of the center large hole and cladding holes are $D = 1.2\Lambda$ and $d = 0.5\Lambda$, respectively. The pitch is $\Lambda = 2.8$ μm. The refractive index of the analyte *n* is 1.40. When silver film with thickness h = 60 nm is coated on the inner surface of the large hole with diameter *D*, the fundamental mode LP_{01} field distribution is given in Fig. 2(b). One finds that the light intensity of the surface of the silver film is obviously larger than its entourage in Fig. 2(b), which indicates that the surface plasmon wave (SPW) is excited since the silver film absorbs the incident light in the condition of the SPR. Besides, the mode of the SPW is not the fundamental mode LP_{01} but the high-order mode LP_{11}. Furthermore, the effective index of the mode LP_{01} is equal to one of the mode LP_{11}. At the same time, the intensity of the plasmon polaritons depends on the operational wavelength and the refractive index of the analyte. The high-order mode LP_{11} of the SPW can also be excited when the horizontal polarization of the fundamental mode LP_{01} field incidences. Furthermore, the polarization direction of the mode LP_{11} is horizontal polarization.

3. Data analysis and discussion

Since the plasmon polaritons exists, the intensity of the guided mode will decrease. So the effective index n_{eff} of the guided mode is complex. The real part represents general refractive index and the imaginary part describes the loss of the