Optical Fiber Technology 20 (2014) 100–105

Contents lists available at ScienceDirect

Optical Fiber Technology

www.elsevier.com/locate/yofte

Novel magnetic field sensor based on magnetic fluids infiltrated dual-core photonic crystal fibers

Jianhua Li *, Rong Wang, Jingyuan Wang, Baofu Zhang, Zhiyong Xu, Huali Wang

Institute of Communications Engineering, PLA University of Science and Technology, Nanjing 210007, China

ARTICLE INFO

Article history:
Received 15 July 2013
Revised 1 December 2013
Available online 20 January 2014

Keywords:
Photonic crystal fibers
Magnetic field sensor
Dual-core
Mode coupling
Magnetic fluids infiltrated

ABSTRACT

Novel magnetic field sensor based on magnetic fluids infiltrated dual-core Photonic Crystal Fibers (PCFs) is proposed in this paper. Inside the cross-section of the designed PCFs, the two fiber cores filled with magnetic fluids (Fe_3O_4) are separated by an air hole, and then form two independent waveguides with mode coupling. The mode coupling under different magnetic field strength is investigated theoretically. A novel and simple magnetic field sensing system is proposed and its sensing performances have been studied numerically. The results show that the magnetic field sensor with 15-cm PCFs has a large sensing range and high sensitivity of 4.80 pm/Oe. It provides a new feasible method to design PCF-based magnetic field sensor.

1. Introduction

Photonic Crystal Fibers (PCFs) were firstly proposed by Knight et al. [1,2]. Since these kinds of new fibers have excellent optical properties such as endlessly single-mode transmission [3], flexible dispersion tailoring and management [4], controllable high birefringence [5], large nonlinear coefficient [6] and so on, they have been widely researched in many applications such as optical communications [7], fiber lasers [8,9], optical devices [10–12], and fiber sensors [13–25].

In these promising applications mentioned above, fiber sensors based on the novel structural PCFs are one of the most potential applications. Especially, temperature, pressure, strain, electric field and magnetic field sensing can be easily realized based on one kind of material-filled structural PCFs. In this kind of PCFs, high sensitive materials are infiltrated into some parts of air holes. For example, Yu et al. [15] filled high thermo-optic coefficient liquid ethanol into air holes of index-guiding PCF and obtained a novel temperature sensor. Its temperature sensitivity of transmission power was about 0.315 dB/°C. Liquid crystal material can also be infiltrated into PCFs and is used as a sensor for electric field intensity measurement [19]. Because the refractive index of liquid crystal can be adjusted by the applied electric field or the varied temperature, high sensitive electric field or temperature sensor can be designed conveniently.

For magnetic field sensing, it is always a big challenge. Usually the magnetic field sensor is designed by Fiber Bragg Gratings (FBG). Several different kinds of magnetic sensors have been reported [20–25]. They are mostly based on the Faraday Effect [20], Lorentzian force [21], magnetostrictive effects [22], polarization properties [23] and other effects of FBG. Recently, the PCF-based magnetic field sensor began to attract research interests. However, it has not been researched deeply as far as we know. In order to increase the sensitivity of magnetic field sensor, magnetic fluids are found to be used in the PCF [25–27]. In the fabrication process of the magnetic-fluid-infiltrated PCFs in experiments, some parts of air-hole were replaced by the infiltrated material when capillaries were used to construct fiber performs, and PCFs were produced by the stake-and-draw method. In addition, we can fill the magnetic fluids into some parts of air-holes after the fiber is finished fabricating. It is the biggest challenge to keep these filled-materials in stabilization and to decrease the fabrication difficulty and cost.

Moreover, multi-core fibers can be easily realized due to its design and fabricated process. There is mode coupling in different independent fiber cores. Especially, the dual-core PCFs and their mode coupling properties were investigated widely. They can be designed for many kinds of optical devices.

In this paper a novel magnetic field sensor based on magnetic-fluid-infiltrated dual-core PCFs is proposed. The two fiber cores filled with magnetic fluids (Fe_3O_4) are separated by an air hole in the cross-section. It will form two independent waveguides. Inside the designed PCFs, the mode coupling of two cores under different magnetic field strength is numerically investigated for magnetic field measurement. Thus, a novel and simple magnetic field

* Corresponding author.
E-mail address: ljhice@163.com (J. Li).

1068-5200/$ - see front matter © 2014 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.yofte.2013.12.008

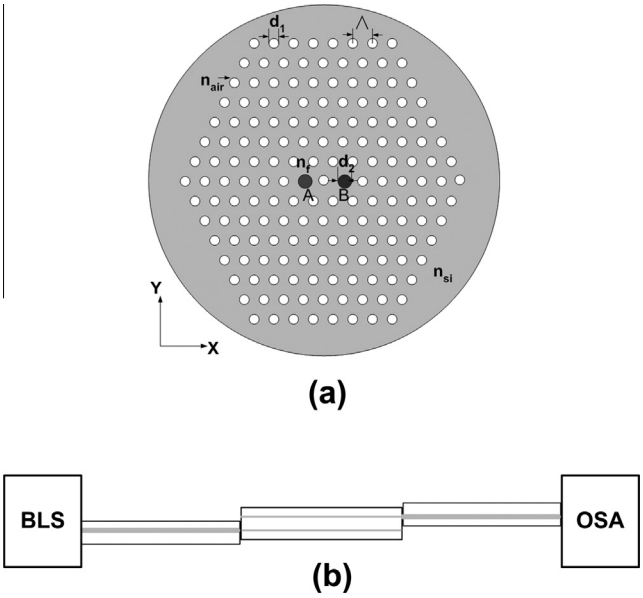

Fig. 1. (a) Cross-section of the designed magnetic fluids infiltrated dual-core PCFs and (b) schematic diagram of the magnetic field sensing system (BLS: broadband light source; OSA: optical spectrum analyzer).

sensing system is proposed. Performances of the sensor have been investigated numerically. The results show that the designed magnetic field sensor with 15-cm PCFs has a large sensing range and high sensitivity of 4.80 pm/Oe. It provides a new method to realize the novel PCF-based magnetic field sensor.

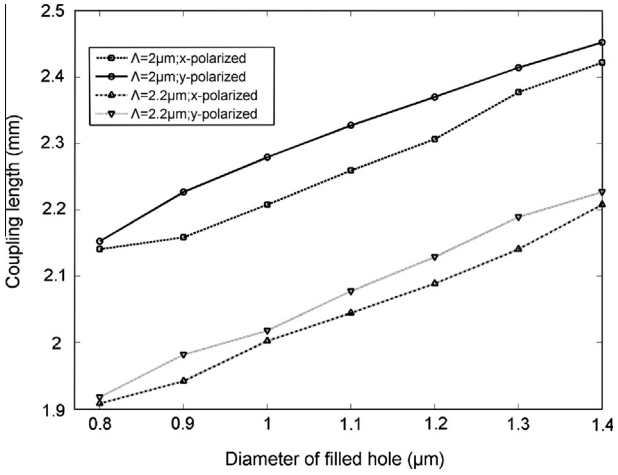

Fig. 3. Coupling length for *x*- and *y*-polarized input light versus diameter of the filled hole.

2. Structure, principle and numerical results

Fig. 1(a) is the cross-section of the designed selectively magnetic fluids infiltrated dual-core PCFs. All the air holes are arrayed in a regular triangular lattice with the hole-pitch Λ. The diameter of the air holes is d_1 and its refractive index is $n_{air} = 1.0$. The background material is silica and its refractive index is $n_{Si} = 1.45$.

Two air holes near the central air hole are filled with magnetic fluids of Fe_3O_4, and then it becomes two new fiber cores. Their

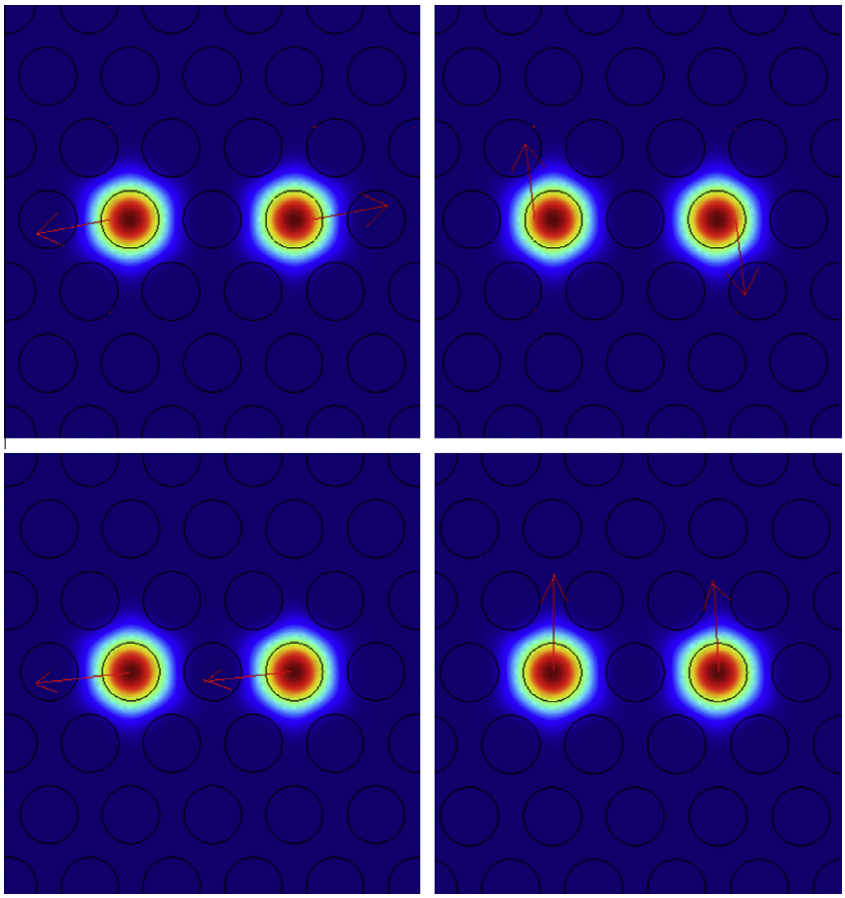

Fig. 2. Electric field for *x*- and *y*-polarized even and odd mode of the dual-core PCFs. Arrow diagrams show corresponding electric field vectors ($d_1 = d_2 = 1.4$ μm, $\Lambda = 2$ μm, and $n_f = 1.4635$).