Optical Fiber Technology 33 (2017) 71–76

Contents lists available at ScienceDirect

Optical Fiber Technology

www.elsevier.com/locate/yofte

Regular Articles

Refractive index sensor based on tapered multicore fiber

Chuanbiao Zhang, Tigang Ning, Jing Li *, Li Pei, Chao Li, Heng Lin

Key Lab of All Optical Network & Advanced Telecommunication Network of EMC, Beijing Jiaotong University, Beijing 100044, China

ARTICLE INFO

Article history:
Received 24 March 2016
Accepted 6 November 2016
Available online 18 November 2016

Keywords:
Fiber optics sensors
Refractive index
Multicore fiber

ABSTRACT

A novel refractive index (RI) sensor based on middle-tapered multicore fiber (TMCF) is proposed and experimentally demonstrated. The sensing structure consists of two singlemode fibers (SMF) and simply spliced a section tapered four-core fiber between them. The light injected from the SMF into the multicore fiber (MCF) will excite multiple cladding mode, and interference between these modes can be affected by the surrounding refractive index (SRI), which also dictates the wavelength shift of the transmission spectrum. Our experimental investigations achieved a sensitivity around 171.2 nm/RIU for a refractive index range from 1.3448 to 1.3774. All sensors fabricated in this paper show good linearity in terms of the spectral wavelength shift versus changes in RI.

1. Introduction

Due to numerous advantages over electronic based sensors, such as immunity to electromagnetic interference, compact size, low cost, remote sensing capability and linear response, optical fiber sensors have been developed in multi-field applications, like structural monitoring [1,2], high temperature sensing [3,4] and biosensors [5,6].

In previous work, there are a number of approaches have been proposed to implement RI sensing, which precisely is the key to achieving bio-photonic sensing. Tapered fiber is one of the commonly used technologies of refractive index sensors [7–13]. Such as tapered single-mode fiber [7,8], or tapered multimode fiber [9,10], and some tapered sensors can increase their sensitivity by nanofilm enhancement [11–13]. Other types of RI sensor such as a Fabry-Perot based fiber optic interferometer [14–16], a fiber Bragg grating (FBG) [17,18], a singlemode-multimode-singlemode (SMS) fiber structure [19–21]. The underlying operating principle of sensors based on SMS structure is multimode interference excited between modes in the multimode fiber (MMF). Despite popularity and high sensitivity, these sensors are stringent fiber fabrication process and the cost are very high due to the use of expensive metal film.

Recently, multicore fiber have shown great potential for sensing applications, like strain [22], curvature [23], temperature [24], and shape sensing [25]. In this paper, we proposed and experimentally demonstrated a novel RI sensor based on an middle-tapered multicore fiber, which simply spliced between two single mode fibers and can be described as SMF-TMCF-SMF structure. The shift in the transmission spectrum depends on the surrounding refractive index solution in the multicore fiber region. And the transmission of the TMCF showing sensitivity to external refractive index, which makes it possible to be an RI sensor. This simple RI sensor structure may suitable for realizing simultaneous multi-parameter measurement with MCF. In addition, we also simulated the sensitivity of cladding mode with different external RI.

2. Working principle

In a SMF28-MCF-SMF28 fiber structure, as shown in Fig. 1.

Interference between these multiple modes within the MCF occurs and dictates the output spectral response of the SMS fiber structure, which is thus affected by the surrounding liquid RI.

In a SMF-TMCF-SMF fiber structure, cladding modes high order modes are excited within the cladding of the MCF section because of the core mismatch between SMF28 and MCF, and the excited modes would travel along the four cores and then are back into the core of SMF-28. It's worth noting that the light also conduct in the four core, however here external refractive index main influencing cladding mode, so we mainly research the change of the cladding mode. Multimode interference for these cladding modes occurs within the MCF section. It is well known that the propagation constant of the cladding mode (corresponding to effective RI) is influenced by the RI of the surrounding environment. Thus, the relative phase difference between two interfering modes can be expressed by,

$$\Delta\varnothing = \frac{2\pi}{\lambda}(\Delta n)L \tag{1}$$

* Corresponding author.
E-mail address: lijing@bjtu.edu.cn (J. Li).

http://dx.doi.org/10.1016/j.yofte.2016.11.008
1068-5200/

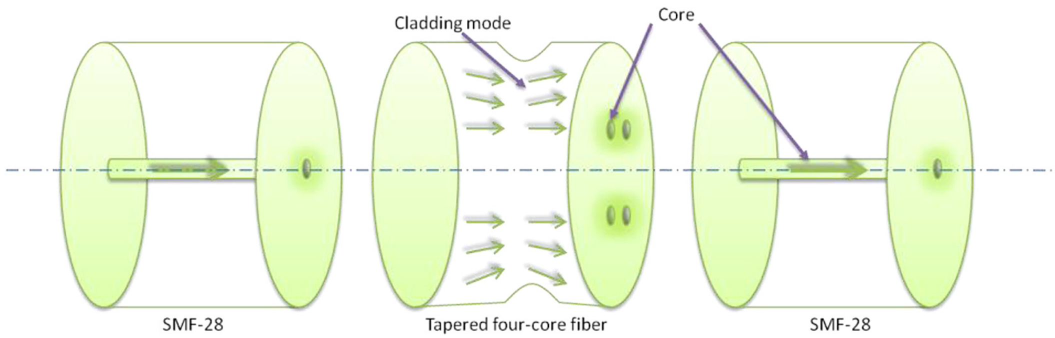

Fig. 1. Schematic diagram of SMF-TMCF-SMF structure with four core fiber.

where λ is the wavelength of the light source, L is the length of the MCF, and Δn is the effective refractive index difference, which can be expressed as,

$$\Delta n = n_{eff}^{co} - n_{eff}^{ou} \tag{2}$$

where n_{eff}^{co} is the effective refractive indices of core mode and n_{eff}^{ou} is the effective refractive indices of higher order modes out of the core.

Assuming that the SMF and MCF are ideally aligned, due to the circular symmetry of the input field, only LP_{0m} modes will be excited in the MCF when light travels from SMF to MCF. If the input light in the SMF has a fundamental mode field distribution $E_1(\mathrm{r})$, then the input field can be decomposed into the eigenmodes LP_{0m} in the MCF when the light enters the MCF section. The field MCF section at a propagation distance L can be described by,

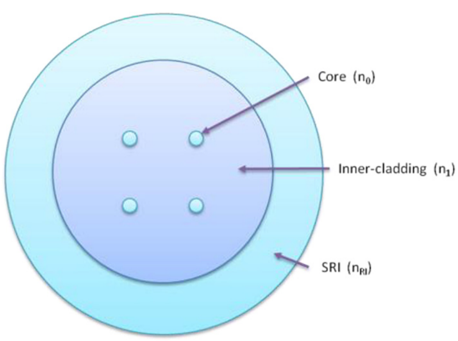

Fig. 2. Configuration of MCF model structure with double-cladding.

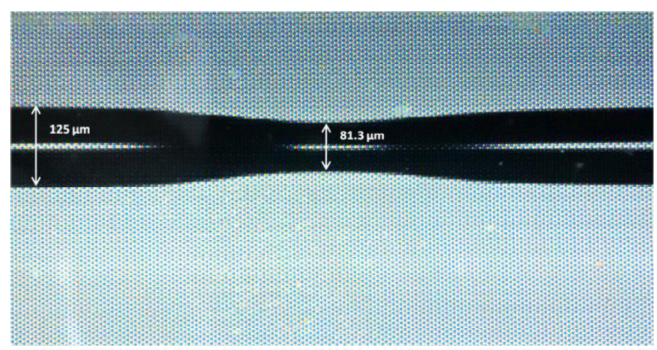

Fig. 4. The picture of tapered MCF.

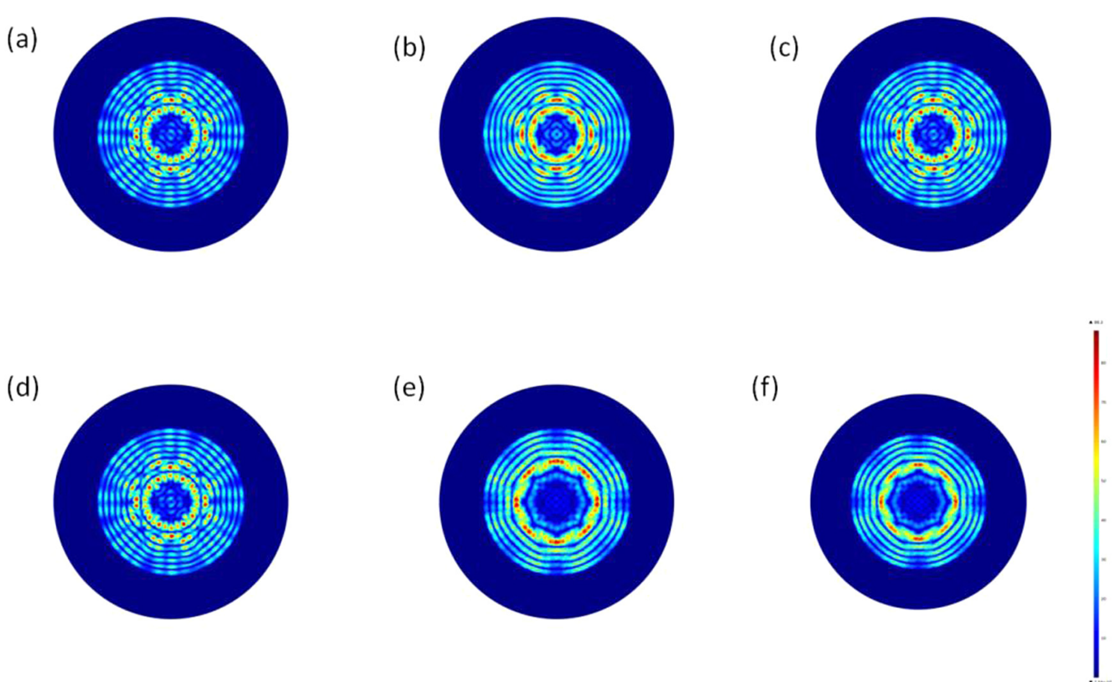

Fig. 3. Mode field distribution for inner cladding are obtained by using FEM with different SRI: (a) 1.33, (b) 1.34, (c) 1.35, (d) 1.36, (e) 1.37, (f) 1.38.