Optics Communications 343 (2015) 131–134

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

High temperature probe sensor with high sensitivity based on Michelson interferometer

Na Zhao [a], Haiwei Fu [a,b,*], Min Shao [a], Xu Yan [a], Huidong Li [a], Qinpeng Liu [a], Hong Gao [a], Yinggang Liu [a], Xueguang Qiao [b]

[a] Ministry of Education Key Laboratory on Photoelectric oil–gas Logging and detecting, School of Science, Xi'an Shiyou University, Xi'an 710065, China
[b] Department of physics, Northwest University, Xi'an 710069, China

ARTICLE INFO

Article history:
Received 16 September 2014
Received in revised form
3 December 2014
Accepted 4 December 2014
Available online 19 December 2014

Keywords:
Temperature measurement
Michelson interferometer
Thin core fiber
Fiber taper bi-taper

ABSTRACT

A novel Michelson interferometer based on a bi-taper is achieved. Such a device is fabricated by splicing a section of thin core fiber (TCF) at one end of single-mode fiber (SMF). Due to the fiber bi-taper at the splicing point of SMF and TCF, the light is coupled into the fiber core and cladding from lead in fiber core. The light will be reflected at the end of the fiber and then will be recoupled back into the lead out fiber core by the fiber bi-taper. While the light returns back to the lead out fiber, the intermodal interference will occur for the optical path difference between core mode and cladding mode. A high temperature sensitivity of 0.140 nm/°C is achieved from 30 to 800 °C, and the linearity is 99.9%. The configuration features the advantages of easy fabrication, a compact size, high sensitivity, wide sensing range and high mechanical strength, making it a good candidate for distant temperature sensing and oil prospecting.

1. Introduction

Temperature is an essential parameter, which can be used for oil prospecting. Nowadays, optical fiber sensing is gradually replacing the traditional temperature measurement which is implemented by electrical-based temperature sensors. Compared with conventional electric sensors, a growing interest on temperature sensors based on optical fibers has been arisen due to their well known advantages of immunity to electromagnetic interference, compactness, high accuracy, ease fabrication, and capability of sensing in harsh environment. At present, a variety of optical fiber sensors [1,2], such as Fiber Bragg grating (FBG) [3,4], long-period fiber grating (LPG) [5,6], Mach–Zehnder interferometer(MZI) [7–13], Fabry–Perot interferometer (F–P) [14–17] have been studied extensively. In particular, with the method of Michelson interferometer [18–20] to measure temperature becomes a new trend. In 2012, Byeong Ha Lee et al. demonstrate a PCF-based Michelson interferometer and the experiment result shows that the sensor's temperature is insensitive [18]. In 2013, Yuanyuan Yang et al. make an in-fiber integrated Michelson–FP composite interferometer, a quartz tube is used to encapsulate the ends of the twin-core fiber and single mode fiber to form the dual extrinsic F–P cavities [19]. In the same year, Kun Yang et al. demonstrate a piece of multimode optical fiber and weld end with silver plated film SMF for temperature measurement from 470 to 600 °C with a sensitivity of 0.120 pm/°C [20].

In this paper, a novel temperature sensor is fabricated by fusion–splicing a bi-taper in thin core fiber (TCF). The bi-taper is fabricated by using a commercial fusion splicer directly. The sensor is robust, and it can be used to decrease the influence of the friction and extrusion force. We present an analysis of the work principle and then experimentally study its temperature response. Experimental result shows that it is a high sensitivity temperature sensor in a wide temperature range, which makes it a good candidate for sensing applications.

2. Principle and fabrication

2.1. Principle

Fig. 1 shows the structural diagram of the in-fiber Michelson interferometer. The section of TCF (1.4 mm) serves as sensing arm and the bi-taper structure in the sensor acts as optical coupler. When the input optical signal propagating in the fiber core

* Corresponding author at: Shaanxi Key Laboratory of Optical Information Technology, Xi'an Shiyou University, and Northwestern Polytechnical University, Xi' an 710065, China.
E-mail address: hwfu@xsyu.edu.cn (H. Fu).

http://dx.doi.org/10.1016/j.optcom.2014.12.012
0030-4018/

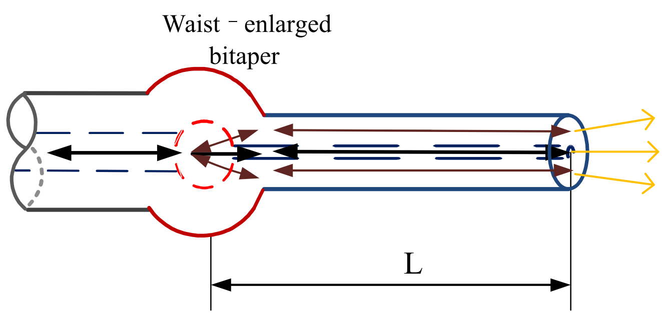

Fig. 1. Schematic diagram of Michelson interferometer.

encounters the bi-taper, several cladding modes are excited due to the bi-taper structure. Both the core and cladding modes travel in the TCF are reflected back from the end surface and recombined in the fiber bi-taper region to interfere with each other. Since different modes get into lead out SMF, the inter–modes interference will occur.

The cumulated optical phase difference induced by the different effective refractive indices of the core and cladding modes can be expressed by,

$$\Delta\phi = \frac{4\pi}{\lambda}\left(\sum_m n_{cladding}^m - n_{core}\right)L \; m = 1, 2, 3 \ldots\ldots \quad (1)$$

where n_{core} is effective refractive index of core mode and $n_{cladding}^m$ is effective refractive index of m-order cladding mode, L is the length of sensor, λ is the center wavelength of the reflection dip.

In combination with Taylor exhibition type, stripe intervals Λ can be expressed as:

$$\Lambda = \frac{\lambda^2}{2\cdot\Delta n_{eff} L} \quad (2)$$

is the effective refractive index difference between the core and cladding modes. The experiment to detect minimum intensity, $\phi = (2k + 1)\pi$, combined with the Eq. (1):

$$4\pi\cdot\Delta n_{eff}\cdot\frac{L}{\lambda} = (2a + 1)\pi \; a = 0, 1, 2, 3 \ldots\ldots \quad (3)$$

When the temperature changes, due to the thermal expansion effect of fiber material, the length of the sensor will change. At the same time, the thermo-optical coeffecients of fiber core and cladding are difference. The impact of these two aspects causes the drift of wavelength according to temperature changes.

2.2. Fabrication

The in–fiber Michelson interferometer is fabricated by using a commercial fusion splicer (Furukawa, S177B). The core/cladding diameters of TCF, SMF used are 5/80 μm and 9/125 μm, respectively. In the structure, the SMF acts as a lead in /lead out fiber, the serves as the optical coupler, and the TCF performs as a sensing arm. The fiber end face is flat by using fiber cleaver (Furukawa, S325) in order to obtain a high reflectivity. The fiber bi-taper can be made by changing the common fusion program of SM–MM, the detailed parameters are as follows: the discharge intensity is choose to be 150, the duration time of discharge is set to be 1100 ms, and the pushing distance is set as 130 μm. Afterward setting the fusion parameters, the two pieces of prepared fibers are applied to be arc discharge and fused. Due to the high discharge intensity and large pushing distance, the fiber bi-taper is fabricated and the diameter is slowly enlarged. The photograph of the bi-taper is displayed in Fig. 2, which is obtained by microscope

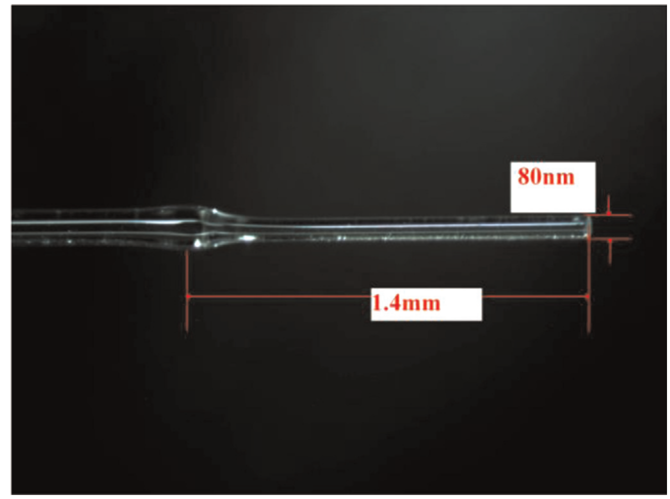

Fig. 2. Microscope image of the temperature sensor used in our investigation.

(Olympus, SZ61) with the magnification of 50. The waist diameter of the fiber at the coupling point is enlarged to about 165–170 μm from the typically 125 μm of SMF, and the bi-taper length is 340–350 μm. The waist of the fiber bi-taper is distended rather than reduced, which contributes to a higher mechanical strength than common structure.

As shown in Fig. 3, the interference fringe pattern is clear and has high fringe visibility. The research shows that the properties of reflection spectrum are mainly decided by the length of sensing arm and the fusion splicing conditions during the fabrication process. However, it is very difficult to control the fusion quality. In order to find out the involved cladding modes which contribute to the interference, the reflection spectra are given the further analysis.

The Fast Fourier Transform (FFT) of the reflection spectra are taken to obtain the spatial frequency spectra, as shown in Fig. 4. They are observed that each of the interference spectra has only one dominant peak which means that there are only one cladding mode and a core mode exist in the reflection spectrum. The dominant peak amplitudes are located at 0.010256 nm^{-1}, 0.020176 nm^{-1}, and 0.071325 nm^{-1} for the sensors with interference length 1.4 mm, 3.0 mm and 10.0 mm, respectively.

By the Taylor expanding at the central wavelength, the phase ϕ can be defined as:

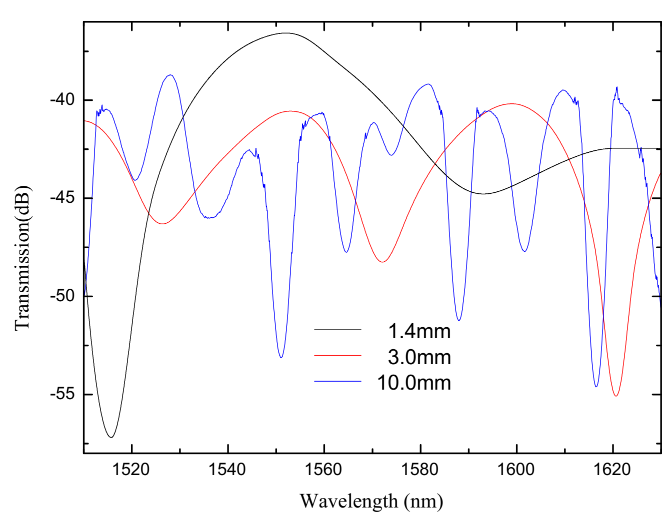

Fig. 3. The wavelength spectra measured with several interferometer lengths.