Optical Fiber Technology 46 (2018) 72–76

Contents lists available at ScienceDirect

Optical Fiber Technology

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

Alcohol-filled side-hole fiber based Mach-Zehnder interferometer for temperature measurement

Yi Xin[a], Min Zhao[a], Hui Zhao[b], Huaping Gong[c], Changyu Shen[c], Chun-Liu Zhao[c], Xinyong Dong[c,*]

[a] China Electronic Product Reliability and Environmental Testing Research Institute, Guangzhou 510000, China
[b] Guangdong Optomedic Technologies Company, Ltd., Foshan 528200, China
[c] Institute of Optoelectronic Technology, China Jiliang University, Hangzhou 310018, China

ARTICLE INFO

Keywords:
Optical fiber sensors
Mach-Zehnder interferometers
Side-hole fibers
Temperature measurement

ABSTRACT

A temperature sensor by using an alcohol-filled side-hole fiber (SHF) based Mach-Zehnder Interferometer (MZI) is proposed and experimentally demonstrated. The SHF-MZI is fabricated by splicing one section of alcohol-filled SHF between two single mode fibers (SMFs). The interference pattern between the core mode and the cladding modes excited at the first fusion splicing point shifts with temperature, due to the temperature-dependent refractive index of alcohol in the SHF, as well as thermo-optic effect and thermal expansion effect of the SHF. Temperature measurement with sensitivity of 105 pm/°C is therefore achieved by detecting resonant wavelength shift of the interference pattern. Meanwhile, the interference properties of the alcohol-filled SHF is investigated and discussed.

1. Introduction

Optical fiber sensors offer many advantages over conventional sensors, such as electrically passive operation, immunity to electromagnetic interference, high sensitivity and low cost. Temperature measurement can be realized with various optical fiber devices including fiber gratings, e.g. fiber Bragg gratings (FBGs) and long period gratings (LPGs) [1,2], and optical fiber interferometers, e.g. Fabry-Perot interferometers Sagnac interferometers and Mach-Zehnder Interferometer (MZIs) [3–5]. Photonic crystal fibers (PCFs), a kind of microstructured optical fibers, have attract considerable attentions for tailoring the transmission properties of optical signals through optical fiber. Side-hole fibers(SHF), a kind of PCF, with two air holes running in parallel to the core in the cladding, was first proposed for pressure measurement in 1986 [6]. It shows optical properties that support to develop various optical fiber devices including optical sensors and optical communication components. By now, all-fiber electro-optic based SHF interferometers have been demonstrated for implementations of pressure, modulation, switching, tuning and short pulse generation devices [7–13]. SHF-based fiber grating devices have also attracted lots of research interest. SHF-based fiber Bragg gratings have been demonstrated for simultaneous measurement of temperature and either pressure or strain, or torsion [14–16]. SHF-based long period gratings have also been characterized and used for temperature and refractive sensing [17,18]. Recently, optic fiber interferometer based on SHF or PCF filled with metals, liquids or polymer, which their properties is sensitive to temperature, have especially attracted great interest in temperature application [19–29].

Last year, a highly sensitive temperature sensor using a Sagnac loop interferometer based on SHF filled with metal was proposed by Eric et al., achieving a high sensitivity of −9 nm/°C, in a range of 22.4–46 °C [19]. Like other optic fiber temperature sensor filling with metal [27–29], polymer [25] or liquid [26], their filling technique is complex, temperature range is small, or their sensing size is long. Temperature measurement with temperature sensitivity of 86.8 pm/°C has been realized in our previous study [24], by using an alcohol-filled SHF Sagnac interferometer. However, Sagnac interferometer is sensitive to surrounding permutation and its temperature sensitivity is relatively low.

In this paper, a temperature sensor by using an alcohol-filled SHF based MZI is proposed and demonstrated experimentally. Compared with no alcohol infiltration, temperature sensitivity is improved from 77.5 pm/°C to 105 pm/°C by alcohol infiltration of the SHF, due to alcohol has a much higher thermo-optic coefficient than air does, and the effective refractive index of SHF cladding decreases with temperature more quickly. Unlike the filling metal technique, its structure is easy fabrication and robust. It is more sensitive than our previously reported temperature sensor based on alcohol-filled SHF Sagnac interferometer [24]. Meanwhile, the interference properties of the alcohol-filled SHF will be investigated and discussed.

* Corresponding author.
E-mail address: xydong@cjlu.edu.cn (X. Dong).

https://doi.org/10.1016/j.yofte.2018.09.018
Received 18 June 2018; Received in revised form 29 August 2018; Accepted 21 September 2018

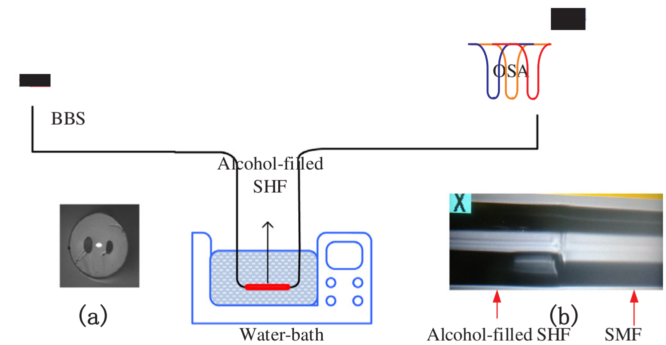

Fig. 1. Experimental setup of the proposed SHF-MZI temperature sensor. Insert (a): SEM of the SHF, Insert (b): side view of splicing point of the alcohol-filled SHF (left) and the SMF (right).

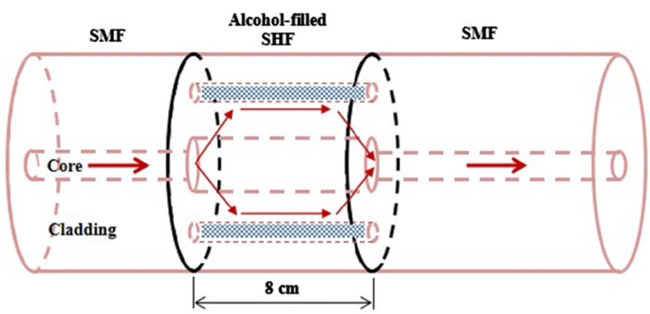

Fig. 2. Schematic of the alcohol-filled SHF-MZI.

2. Experimental setup and principle

Fig. 1 presents the experimental setup of the proposed temperature sensor by using an alcohol-filled SHF based MZI. It consists of a broad band source (BBS), an 8-cm-long alcohol-filled SHF sandwiched between two SMFs, and an optical spectrum analyzer. The alcohol liquid, with its refractive index depending on temperature at a rate of about -4×10^{-4}/°C, was filled into air holes of the SHF by capillary force to enhance temperature sensitivity of the SHF-MZI. The all alcohol-filled SHF is immersed in the water bath, as a temperature sensor. The scanning electron micrograph (SEM) of the SHF's cross section is shown in Fig. 1 (a). There are two ellipse holes located in the cladding both side of the core. Both ends of alcohol-filled SHF were spliced to SMF using a regular arc splicing machine (Fujikura FSM 60). Fig. 1(b) shows the profiles of fusion splicing point between alcohol-filled SHF and SMF.

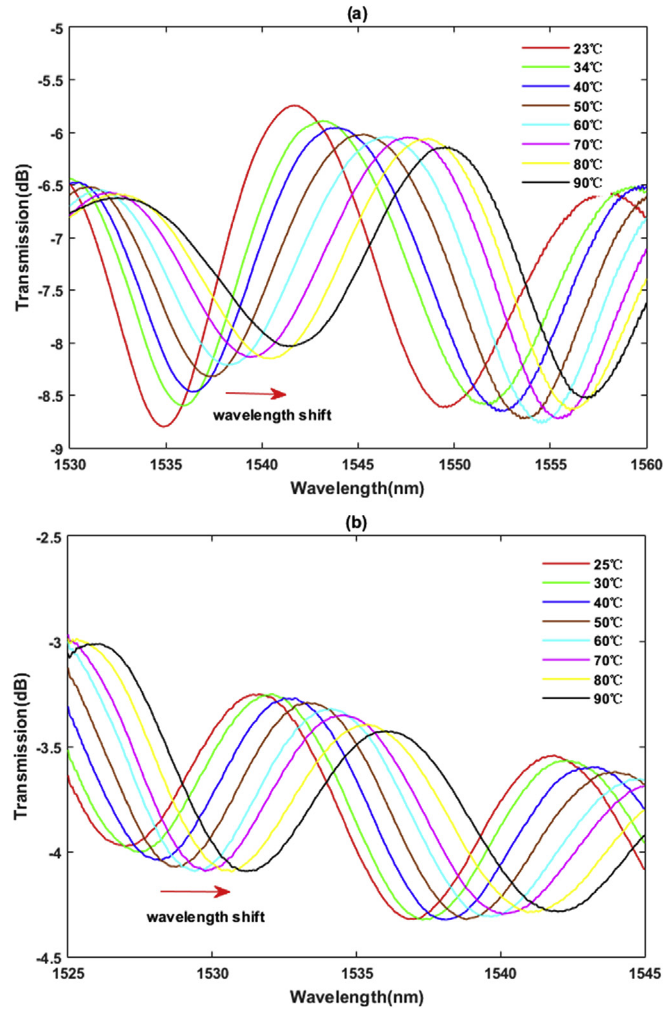

Fig. 4. Transmission spectra of SHF-MZI under different temperature (a) with and (b) without alcohol infiltration.

Fig. 2 shows the operation principle of the proposed sensor. When

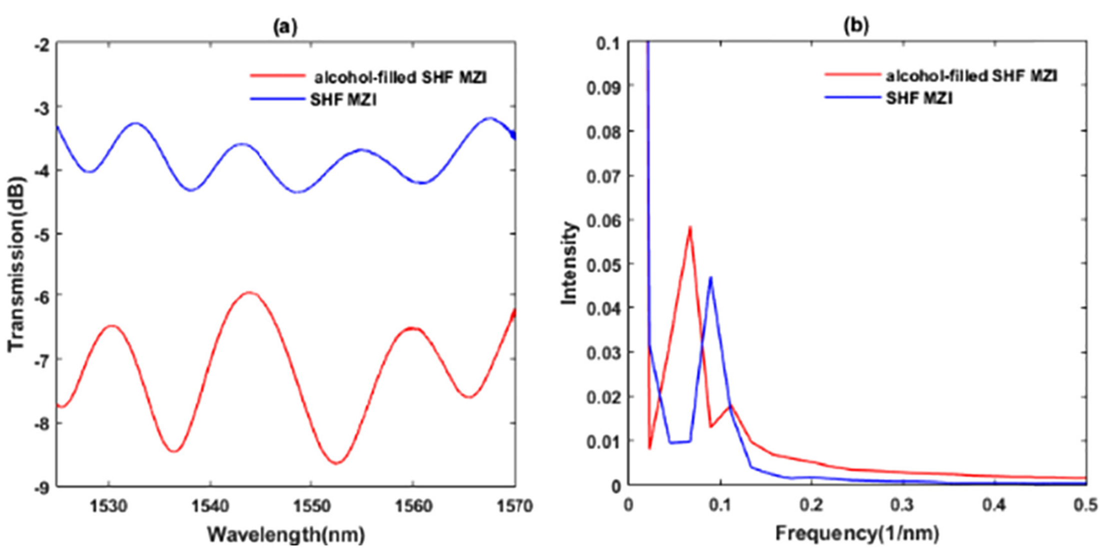

Fig. 3. (a) Transmission spectra of SHF-MZI with and without alcohol infiltration at 40 °C and (b) its spatial frequency spectra.