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Research on simultaneous measurement of refractive index and temperature comprising few mode fiber and spherical structure

Zhengrong Tong *, Yimei Zhong, Xue Wang, Weihua Zhang

School of Electrical and Electronics Engineering, Tianjin Key Laboratory of Film Electronic and Communication Devices, Tianjin University of Technology, Tianjin 300384, China

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ABSTRACT

A simple sensor for simultaneous measurement of refractive index (RI) and temperature based on Mach–Zehnder interference (MZI) is proposed and studied experimentally and theoretically. It consists of a section of few mode fiber and two spherical structures. The two spherical structures act as couplers that can excite high-order core modes and recouple the high-order core modes with the cladding modes back into the core. Two selected dips of the interference spectrum shift with the variation of RI or temperature, and simultaneous measurement of temperature and RI can be realized by means of a sensitivity coefficient matrix. The temperature sensitivity is 0.054 nm/°C as high as in the range from 25 °C to 80 °C, and the RI sensitivity is −27.77 nm/RIU in the range from 1.335 to 1.398. The proposed MZI is characterized by low cost, easy fabrication, and good robustness.

1. Introduction

Optical fiber sensors, especially based on the MZI, have attracted great attention in various fields due to its merits of small size, good stability, low power consumption and resistance to electromagnetism. In recent years, fiber optic sensors based on different coupling structures have been demonstrated, such as single mode fiber (SMF)-multimode fiber (MMF)-SMF structure [1,2], SMF-tapered Bragg fiber-SMF [3,4], double fiber down-tapers or up-tapers [5,6], fiber lateral-offset splicing [7] and combination structures [8]. And these modal interferometric sensors are used to measure various parameters in medical diagnosis, food quality testing, physical measurements chemical analysis and environmental monitoring. Miao et al. reported sensor for relatively humidity measurement based on tapered square no-core fiber coated with SiO_2 nanoparticles [9]. Sensors constructed by a seven core optical fiber sandwiched between two short segments of multi-mode fiber (MMF) was proposed for the measurements of temperature and curvature [10]. Zhang et al. presented a bending vector sensor based on lateral-offset and S type fiber taper [11]. Zhao et al. put forward an optical fiber RI sensor based on SMF–MMF–SMF (SMS) configuration which uses etched multimode fiber (MMF) [12]. However, among the aforementioned schemes, due to the thermal effect and thermal expansion effect of the optical fiber, the measurement of refractive index, curvature, strain and other parameters will be affected by the temperature, in order to eliminate the temperature cross effect, sensors based on dual-parameters simultaneous measurement is put forward and studied by more and more experts and scholars. For instance, the fiber sensor constructed by sandwiching a straight section of the polarization maintaining fiber between two peanut structures for simultaneous measurement of temperature and strain is proposed [13]. Zhou proposed a sensing structure constructed by combining a PCF-based MZI with a fiber Bragg grating (FBG) [14]. Bin Yin et al. proposed structure simply involves a section of the single-mode fiber (SMF) spliced to two sections of multimode fiber (MMF) and lead-in and lead-out SMFs. But this article does not analyze the cross effects of temperature and strain , and it is possible to be affected by temperature when the strain sensing characteristics experiment is conducted [15]. Q. Yao et al. cascaded a core-offset MZI and a FBG to achieve simultaneous measurement of refractive index and temperature [16]. However, there are some disadvantages,for example, the temperature sensitivity is low and the FBG is expensive.

In this paper, we proposed and experimentally demonstrated a simple and compact fiber optic sensor for simultaneous measurement of temperature and RI. The sensor is formed by the integration of a segment of FMF with two spherical structures. By monitoring the wavelength shifts of two selected dips, simultaneous measurement of temperature and RI can be achieved. The proposed sensor has the advantages of easy to construct, and the capability to measure RI and temperature simultaneously, which are desirable features in RI measurement.

* Corresponding author.
E-mail address: tjtongzhengrong@163.com (Z. Tong).

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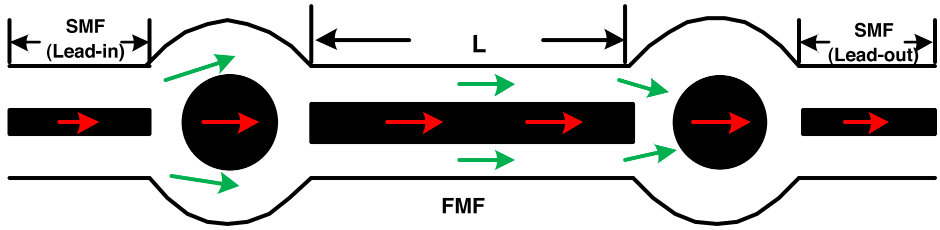

Fig. 1. Schematic diagram of the proposed MZI.

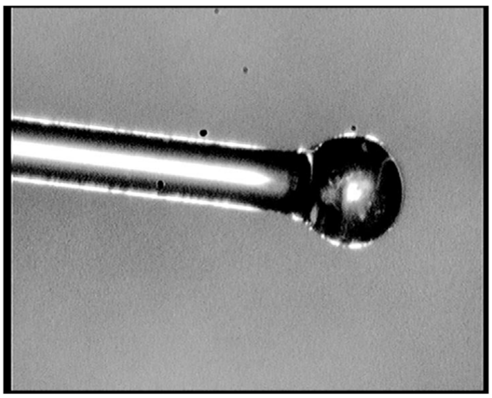

Fig. 2. The micrograph of the spherical structure.

2. Sensor design and fabrication

The schematic diagram of the proposed MZI for simultaneous measurement of temperature and RI is depicted in Fig. 1. It consists a few mode fiber between two spherical structures.

The spherical structures are fabricated by commercial fusion splicer (S178C, Fitel, Japan). The two spherical structures are obtained by using manual splicing program. First, a section of SMF (8.2 μm/125 μm) is cleaved and put into the fiber fusion splicer, apply arc discharge to the end of a SMF, the end of SMF will be soften and become spherical-shape, as shown in Fig. 2. (The parameters of the arc discharging are as follows: the discharge duration is 12 100 ms; the discharge intensity is 120 bit.) Second, the two ends of a section of FMF are fused with two spherical structures by normal splicing after manual alignment. (The parameters of the arc discharging are as follows: The discharge time is 12 100 ms; the discharge intensity is 85 bit.) And then, it is measured accurately by a microscope after the structure is fabricated.

The same discharge parameters can obtain lots of spherical structures. Each spherical structure is observed under a microscope to get its size which is shown in Table 1. It can illustrate from the table that each spherical structure is similar in size. The relative standard deviation is less than 1.18% and the fabrication process is repeatable.

The basic principle of the optical fiber sensor is when the external parameters (such as temperature, refractive index, liquid level, stress, displacement, etc.) change, some characteristic parameters of the optical fiber will transform. So we can through observing some characteristics parameters of optical fiber to judge its environment external parameters change, thus achieve the purpose of sensing.

When the incident light passes through the first spherical structure, the core modes of FMF are excited due to the abrupt change of the fiber structure, and then the excited core modes are transmitted along the FMF together with the cladding modes, finally are recoupled at the second spherical structure. $\Delta\varphi$ is the phase difference between the core modes and cladding modes after transmitting the distance of L, which can be expressed as follows:

$$\Delta\varphi = 2\pi \frac{\left(n_{co} - n_{cl}\right) L}{\lambda} \tag{1}$$

where n_{co} and n_{cl} are the effective refractive indexes of the core modes and the cladding modes, L is the length of FMF between the two spherical structures, and λ is the operating wavelength. When $\Delta\varphi = (2m+1)\pi, m = 0, 1, 2\ldots$, the transmission dips are located at

$$\lambda_{dip} = \frac{2}{2m+1}\left(n_{co} - n_{cl}\right) L \tag{2}$$

With the change of temperature and RI at the same time, the variation of the dip $\Delta\lambda$ can be expressed as follows:

$$\lambda_{dip} + \Delta\lambda = \frac{2}{2m+1}[(n_{co} + \Delta n_{co}) - (n_{cl} + \Delta n_{cl})](L + \Delta L) \tag{3}$$

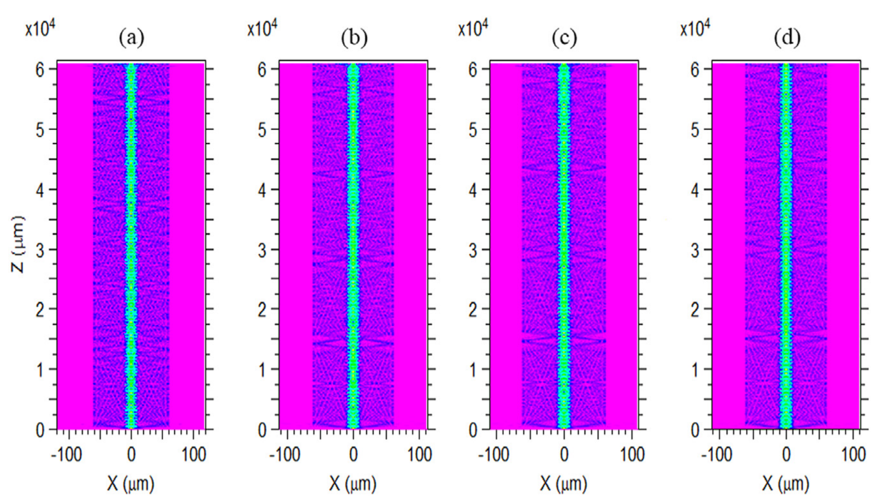

Fig. 3. Simulated mode field distribution of the light propagating in the sensor under different ambient RI levels of (a) 1, (b) 1.33, (c) 1.38, and (d) 1.44, respectively.