Infrared Physics & Technology 81 (2017) 170–174

Contents lists available at ScienceDirect

Infrared Physics & Technology

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

Regular article

Simultaneous measurement of dual-points seawater temperatures using highly-birefringent elliptical-core fibers

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HIGHLIGHTS

- Highly-birefringent elliptical-core fibers are used for simultaneous measurement of dual-points seawater temperatures.
- The sensor could adjust the distance flexibly to adapt the ocean phenomena measurement.
- The minimal temperature resolution is 0.016 °C and the temperature sensitivity is −245 nm/°C.

ARTICLE INFO

Article history:
Received 16 July 2016
Revised 5 January 2017
Accepted 5 January 2017
Available online 7 January 2017

Keywords:
High birefringence
Sagnac loop
Temperature sensor
Optical fibers

ABSTRACT

Dual-points temperature measurement in seawater is demonstrated based on a seawater temperature sensor assembled by the highly-birefringent elliptical-core fiber (HBECF). The theoretical and experimental transmission spectra of the sensor are studied respectively, which shows good agreement with each other. And a matrix equation is established by analyzing the experiment results, by which the temperature changes can be obtained by measuring the wavelength shifts of spectra. The minimum temperature change that can be detected is 0.016 °C and the measurement error is about 0.1%. The advantages of simple structure, high accuracy, high sensitivity, fast response and anti-electromagnetic interference make the sensor meet the demands of seawater temperature measurement.

1. Introduction

Highly-birefringent elliptical-core fiber (HBECF) has been widely used in field of communication because of the good performance in polarization-maintaining. Recently, many all-fiber sensors based on the HBECF have been developed to measure a variety of physical parameters, such as temperature, strain, surface plasmon resonance and torsion [1,2, 7–12]. For example, Sun et al. [3] have fabricated a kind of elliptic microfiber with CO_2 laser, and a higher sensitivity is obtained to measure refractive index. In addition, HBECF sensors based on Sagnac loop mirror are passive detectors and they can realize continuous real-time monitoring [4]. Wa et al. have improved the refractive index sensitivity to 20, 745 nm/RIU by cascading two Hi-Bi microfibers instead of a single microfiber [5]. Passos et al. have inserted high-birefringence fiber into loop mirror to get a high-sensitivity strain sensor. And their work is pretty original and enlightening in the high-birefringence fiber sensor field [6].

Seawater temperature is a key parameter in ocean dynamics and ocean-atmosphere interaction [13]. Especially, in the investigation of internal waves, the seawater temperature data are required to be high sensitive on large spatial distances apart. However, in the current methods, such as CTD (Conductivity-temperature-depth sensor) device, satellite remote sensing and traditional reversing thermometer have some limitations in seawater temperature sensitivity and multi-point continuous measurement [14–16]. Distributed Fiber Bragg Grating temperature sensors have the advantage of continuous multi-point measurement of temperature, but its sensitivity still cannot fully meet the requirements [17]. The distance between the two positions is the main limiting factor of simultaneous temperature measurement of meso/micro scale ocean phenomena like ocean internal waves and seawater stratification.

Therefore, we propose a HBECF seawater temperature sensor based on Sagnac loop mirror to measure dual-points seawater temperature continuously and simultaneously. The distance between two measuring points can be adjusted flexibly to adapt the ocean phenomena measurement. We found that there is a special and interesting phenomenon of the new structure: The temperature changes of HBECFs at different positions are reflected in one spectrum. What is more important, the spectral shifts of Dips (The sunken points whose light intensity is lower, shown in Figs. 3, 5, 6 and 7) are different. We believe that the phenomenon we found here

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http://dx.doi.org/10.1016/j.infrared.2017.01.003
1350-4495/

may bring new ideas for other optical fiber sensors to extend measurement points. By measuring the shifts of Dips in the different spectra, an empirical matrix equation is obtained to calculate the temperature changes of the two HBECFs with the data of spectral shifts. Compare with our previous work [7], our new work is concerned with measuring the temperature change of two different positions at the same time. Adding a HBECF in Sagnac loop mirror is not a simply improvement, the spectrum change caused by adding another HBECF in the Sagnac loop is complex and diverse. We have established a new theoretical model and a new method to process experiment data.

2. Experiment system of dual-HBECFs temperature sensor based on Sagnac loop mirror

Two HBECFs with different lengths are immersed in seawater on the temperature controllers, and connected in series to the Sagnac loop mirror. Fig. 1 is the schematic diagram of dual-HBECFs temperature sensor. The incident lights from Broadband Source (BBS) are split into clockwise and counterclockwise beams by a 3 dB coupler. The two beams pass through the polarization controller (PC) and the HBECFs from opposite directions. Then the interference spectrum of the two beams is received by a Optical Spectrum Analyzer (OSA). The type of the OSA we used is AQ6370C TELECOM OPTICAL SPECTRUM ANALYZER from Yokogawa Meters & Instruments Corporation whose highest resolution is 4 pm. Due to the characteristics of the Sagnac loop mirror, there is no need to process the beams by polarizers and the state of polarization from the BBS is maintained as elliptically polarization. Including the HBECFs, all of the devices are connected by single-mode fibers.

The HBECFs we used here are PME1300-10 highly-birefringent elliptical-core fibers. It is a polarization-maintaining fiber production of IVG Company in Canada which has an elliptic core wrapped in a diameter of 125 μm cladding. The long axis of HBECF core is 13 μm and the minor axis is 8 μm as shown in Fig. 2. By analyzing the energy distribution of the HBECF, we found that there are two different orthogonal modes in HBECF when the incident light is transmitting. The simulative effective refractive index difference between the two orthogonal modes (Δn) is 1.901×10^{-4} which is obtained under the simulation condition of 20 °C and 1550 nm. The spectrum simulated by Δn is basically consistent with the experimental spectrum in the aspect of FSR (Free spectrum range) and the wavelength of Dips. The thermal expansion coefficient of HBECF is 5.5×10^{-7}/°C which is provided by IVG Company of Canada. The temperature changes conduct into the elliptic core and produce thermal expansion to HBECF, which changes the effective refractive index of the two orthogonal modes. So the variation in optical path difference causes spectral shifts.

3. Experimental results and analysis

3.1. Measurement of each point seawater temperature changes

According to Fig. 1, the variable-controlling approach was used to get the relationship between temperature change and spectral shifts. When the temperature of $HBECF_2$ is maintained at 18.02 °C by the seawater temperature controller (SCM96, Sunny Precise Instruments (Shanghai)) and the temperature of $HBECF_1$ is selected to change from 18.36 °C to 36.41 °C quickly, the transmission spectra are scanned at different temperatures around 1620 nm as shown in Fig. 3a. Likewise, keep the system structure parameters unchanged, the temperature of $HBECF_1$ is maintained at 18.07 °C and the temperature of $HBECF_2$ is selected to change from 17.33 °C to 36.14 °C quickly, the transmission spectra are shown in Fig. 3b.

When the temperature of $HBECF_1$ increased only, the spectra move to the shorter wavelength integrally. The wavelength shifts of Dip B are significantly larger than the wavelength shifts of Dip A. However, when the temperature of $HBECF_2$ increased only, although the spectrum is still shifting to shorter wavelength, the spectrum shift of Dip A is significantly larger than Dip B. The phenomenon we find here is worth studying, because it is different from other study in the field of optical fiber sensors. It can be concluded that the temperature variations of $HBECF_1$ and $HBECF_2$ produce different responses to the spectral shifts. Based on this point, we can construct a matrix equation to calculate the temperature changes of $HBECF_1$ and $HBECF_2$ by measuring the wavelength shifts of Dip A and Dip B.

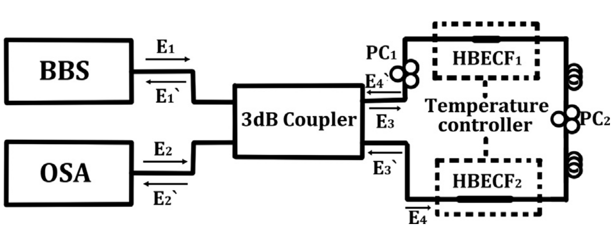

Fig. 1. Schematic diagram of dual-HBECFs temperature sensor based on Sagnac loop mirror.

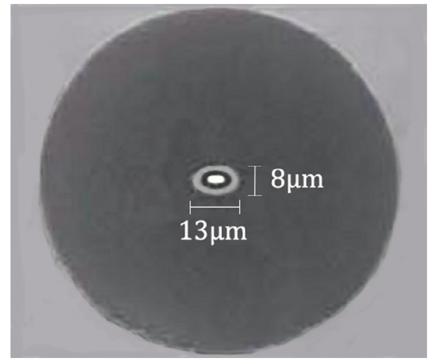

Fig. 2. Cross-section view of PME1300-10.

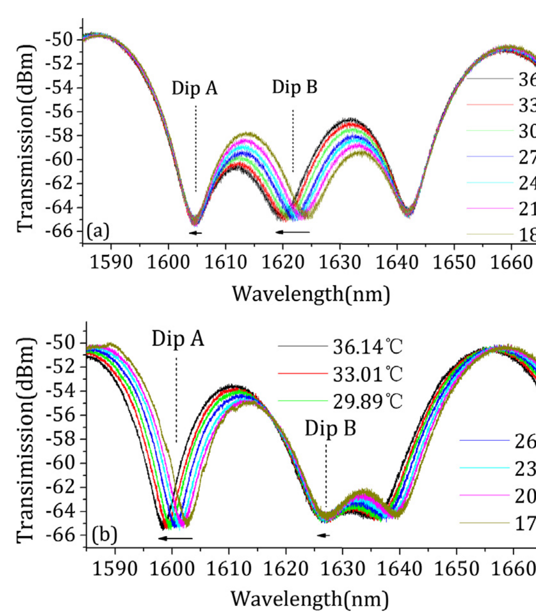

Fig. 3. Transmission spectra of dual-points seawater temperature sensor based on Sagnac loop mirror. (a) The temperature of $HBECF_1$ increased only. (b) The temperature of $HBECF_2$ increased only.