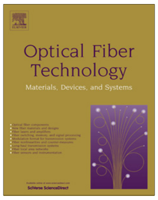
Optical Fiber Technology 36 (2017) 237–244

Contents lists available at ScienceDirect

Optical Fiber Technology

www.elsevier.com/locate/yofte



Regular Articles

Temperature-independent evanescent wave sensor made of a stress-released silica optical fiber taper

Yongxi He, Yingguang Li *, Nanya Li

College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China

ARTICLE INFO

Article history:
Received 11 October 2016
Revised 1 April 2017
Accepted 2 April 2017

Keywords:
Evanescent wave sensor
Silica optical fiber taper
Temperature independency
Stress

ABSTRACT

Based on a cyclic heating-cooling treatment method, a temperature-independent silica optical fiber evanescent wave sensor is proposed. The cyclic heating-cooling treatment process could significantly release the residual stresses in the taper, achieving a high measurement accuracy in the temperature range of 20–200 °C. After the treatment, the relative light intensity[1] (RLI) variation was 0.03 dB in the temperature range of 20–200 °C. The RLI variation of the tapered silica fiber-optic evanescent wave[2] (TSFEW) sensor was reduced by 86% compared with the untreated TSFEW sensor. Two kinds of typical treatment processes were studied by contrast experiments to further explore effective treatment process of temperature-independent TSFEW sensors. The effectiveness of the temperature-independent TSFEW sensor was validated using sucrose solutions at different temperatures. The mechanism of cyclic heating-cooling treatment method for eliminating the effect of temperature on TSFEW sensors was analyzed.

1. Introduction

Tapered fiber-optic evanescent wave sensors are widely applied in chemistry [1], biochemistry [2], life sciences [3], and environmental research [4]. This kind of sensors provides fast and reliable real-time monitoring in the measurement of solution concentrations and chemical component analysis [5]. Because light guided in a tapered fiber has a significant fraction of power propagating in evanescent wave, this kind of sensors is highly sensitive to the surroundings [6,7]. The tapered silica fiber-optic evanescent wave (TSFEW) sensors have gained many interests due to their high mechanical strength and excellent high-temperature characteristic [8,9]. However, the TSFEW sensors are highly temperature sensitive and may lead to a failure of measurement in variable temperature environment.

Several techniques have been developed to realize a temperature-independent measurement application of TSFEW sensors. Xu et al. [10] demonstrated a temperature-independent strain sensor based on the use of a chirped fiber Bragg grating (CFBG) written in a tapered silica optical fiber. Frazão et al. [11] proposed a method for strain-temperature discrimination based on two CFBGs written in a fused biconical fiber taper. The two kinds of sensing structure require a perfect match between the geometry of tapered region and CFBG, which brings extra complexity to the application of TSFEW sensors. Salcedadelgado et al. [12] reported a temperature-insensitive refractive index (RI) sensor based on mode interferometer of non-adiabatic tapered optical fiber. Gouveia et al. [13] also reported a fiber optic interferometry system, which could achieve a temperature-independent RI measurement. In the vast majority of temperature-insensitive TSFEW sensors based on mode interferometer, measured parameters are correlated with a relative shift of a peak, dip, or interference pattern. To quantify such a shift, an interrogation system that entails complex and expensive devices is required. Almost all of the work has focused mainly on reducing the effect of temperature on the measurement of TSFEW sensors by temperature compensation or mode interferometer, and few studies have been reported on the effect of stresses on the sensing performance of TSFEW sensors when they are subjected to temperature variations [14]. Furthermore, the effect of optical fiber coating on the temperature independency of TSFEW sensors has not been examined, and the previous research of the authors discovered that the measurement consistency of TSFEW sensors is not stable in varying temperature environment. Thus, an understanding of the temperature-dependent performance of TSFEW sensors is required to facilitate the fabrication and application of high-quality TSFEW sensors. And it would be necessary to develop easy-fabricated and low-cost TSFEW sensors for temperature-independent sensing.

---

* Corresponding author.
E-mail address: liyingguang@nuaa.edu.cn (Y. Li).

[1] RLI.

[2] TSFEW.

http://dx.doi.org/10.1016/j.yofte.2017.04.001

Within this work, a temperature-independent evanescent wave sensor made of a stress-released silica optical fiber taper is proposed. The effects of residual stresses on the temperature-independency of TSFEW sensors are analyzed. The effects of optical fiber coating on the temperature independency of TSFEW sensors are examined by contrast experiments. To further explore effective treatment process of temperature-independent TSFEW sensors, two typical treatment processes are studied. The temperature-independent TSFEW sensors are operated at 250 °C to study the sensing stability, and they are validated using sucrose solutions in different temperatures.

2. Preparation of the tapered fiber

When guided light is transmitted in a standard optical fiber through the total reflection, the intensity of evanescent wave decays to almost zero at the outer surface of the cladding, making it insensitive to the surrounding specimens [15]. One possibility to make the evanescent wave interact with external specimens is getting the fiber tapered. Fiber tapers can not only reduce the diameter of cladding, but also strongly enhance the power fraction in the cladding in the form of evanescent wave [16,17], and thus, the output light intensity is sensitive to the small changes of external medium. The schematic diagram of the taper structure in TSFEW sensor is shown in Fig. 1. The geometrical dimensions of the taper are characterized by using the cladding diameter d_1, core diameter d_2, waist diameter d_3, taper length L, transition zone length b and a.

The fabrication system of optical fiber taper is shown in Fig. 2 (a). Two horizontally movable optical fiber clamps were used to support and hold optical fibers when they were heated and stretched. The horizontal movements were realized by the combination of ball screw and stepper motor. Two programmable motor drivers and controllers were deployed to adjust the movement rate. In order to ensure the simultaneity of the two movements of optical fiber clamps, an infrared remote (IR) controller and two receivers were used. Through modern digital coding techniques, the button function of the infrared remote controller was coded with corresponding instructions to achieve a remote control. The alcohol gas flame was used as heating source to heat optical fibers. The temperature of the top part of the flame is approximately 1000 °C, which is up to the softening temperature of silica optical fibers (~990 °C) [18].

Fig. 2(b) shows the schematic diagram of the setup for the fabrication of tapered fibers. To ensure the optical consistency of the tapered fibers, a batch of standard optical fibers was stretched simultaneously. In this work, two different tapers were investigated and shown in Table 1. Tapers with different stripped length of coating were prepared to demonstrate its effects on the temperature independency of TSFEW sensor. The TSFEW sensors were made from step-index optical fibers (Corning SMF-28 Ultra Fiber, $d_1 = 125\ \mu m$, $d_2 = 9\ \mu m$) by using a transverse scanning method. The movement rate of optical fiber clamps was 0.5 mm/s while the gas flame was oscillating between limit switches. After tapering process, every tip end of the tapered fibers was connected to

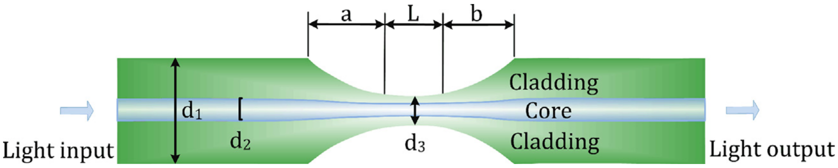


Fig. 1. The schematic diagram of the taper structure in TSFEW sensor.

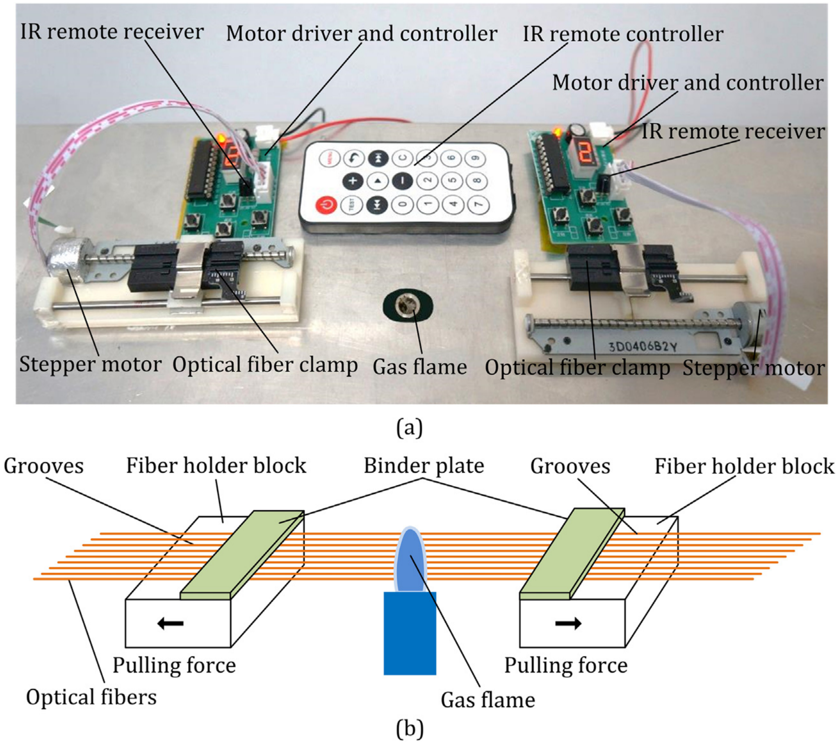


Fig. 2. (a) The optical fiber taper fabrication system, (b) the schematic diagram of the setup for the fabrication of tapered fibers.