Sensing characteristics of tapered High-Birefringent optical fiber

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ABSTRACT

A high-birefringent fiber (HBF) was tapered as adiabatic in sequence steps by utilizing a CO_2 laser and its birefringence was measured in fiber loop mirror (FLM) setup. The birefringence of tapered section and total sensor was obtained to be -8.02×10^{-2}, and 2.46×10^{-4}, respectively. Then, refractive index (RI) sensitivity increased and temperature sensitivity of the tapered Hi-Bi fiber (THBF) decreased. The sensitivity of the proposed FLM interferometer for RI changes in the range from 1.3380 to 1.3470 was measured to be 389.85 nm/RIU. The temperature sensitivity in the range from 50°C to 90 °C was measured to be -1.19nm/°C.

Keywords: high-birefringent fiber, taper, birefringence, refractive index, temperature.

1. INTRODUCTION

Optical biochemical fiber sensors have been studied based on a range of different concepts. The main physical phenomena exploited for the realization of biochemical fiber sensors are absorption and fluorescence. Another well-known concept for detection of biochemical parameters is based on its interaction with the evanescent field (EVF) of the light that travels in an optical fiber. The amplitude of the EVF is typically very low in a normal single mode fiber (SMF), but it can be enhanced significantly by tapering, and thereby the interaction of the transmitted light and the analyte lying on the taper is enhanced [1]. The measurement of changes in refractive index (RI) enables to continuously monitor unlabeled biomolecular interactions occurring at their interface which has many applications such as the study of a molecular structure and the identification of organic compounds in the medical, pharmaceutical, fluid, petrochemical and food industries [2]. Fiber loop mirrors (FLMs) are attractive devices and very useful components for the implementation of optical devices and systems. The FLM is formed by a splice between the output ports of a directional optical coupler. When a section of highly birefringent fiber (HBF) is spliced inside of the FLM, a path unbalance is introduced between the light that propagates along different polarization eigenaxis and an interferometric spectrum is observed at the output [3].The FLM interferometer has many advantages, such as high sensitivity to external perturbation changes, polarization independence to input light, low insertion loss, electromagnetic immunity, and high measuring precision [3]. In optical sensing, besides the gyroscope application, it has been used in temperature and strain measurements [4-5].
In this paper sensing parameters of an adiabatic tapered HBF (THBF) in FLM setup was characterized.

2. EXPERIMENTS AND RESULTS

2.1 Experimental setup and tapering of Hi-Bi fiber

For characterizing of THBF and study of changing birefringence in during process of tapering, experimental setup figure 1 was used. The proposed setup consists of a broadband light source, an optical spectrum analyzer (OSA) with a maximum resolution of 10 pm, a 50:50 power splitting directional coupler, a polarization controller (PC) and a THBF inserted into the loop. The THBF has three parts, a tapered section between two HBF sections. The transmission spectrum of the fiber loop is approximately a periodic function of the wavelength, namely

$$T(\lambda) = 4\alpha^2 \sin^2 \frac{\Gamma}{2} \sin^2 2\theta \cos^2 (\frac{\pi BL}{\lambda}) \tag{1}$$

Where α is the splitting ratio of the coupler, Γ is the retardance and θ is the orientation of the axes of the wave plate with respect to the laboratory coordinates. B is considered as initial birefringence of HBF which is expressed as $B = \left| n_x - n_y \right|$, where n_x, n_y are the effective RI of fast axis and slow axis of HBF, respectively. L is the length of HBF. When HBF is tapered, the birefringence of the tapered section and total birefringence of THBF can be calculated with below equations:

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$$B_{Taper} = (\frac{\lambda^2}{\Delta\lambda} + BL) / L_{Taper} \quad (2)$$

$$B_{Total}(L + L_{Taper}) = \frac{\lambda^2}{\Delta\lambda} \quad (3)$$

where B_{Taper}, B_{Total}, L_{Taper}, λ, and $\Delta\lambda$ are taper birefringence, total birefringence, tapered length, central wavelength and wavelength spacing, respectively. In this particular case a commercial PANDA HBF (HB 1550-T) was used.

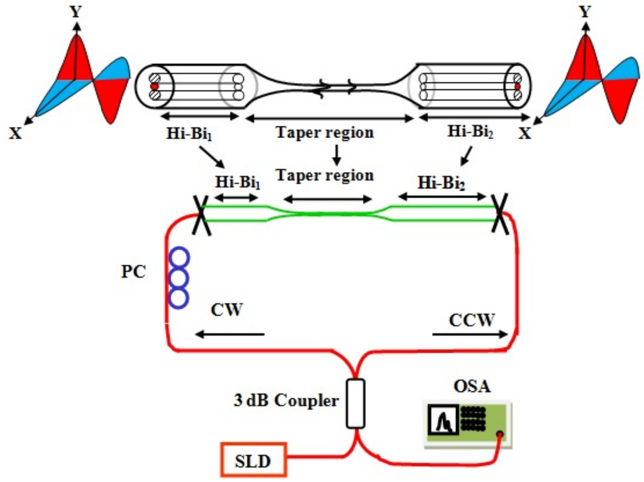

Figure 1. Schematic setup for fiber loop mirror interferometer based on the THBF

In figure 1, the broadband light at the input port travels into the coupler and splits into two counter-propagating beams. These two light beams propagate in the clockwise and counter clockwise directions, respectively, and meet again in the coupler to induce interference. The interfered beams after the coupler also split to propagate into the output port and input port, respectively. The characteristics of these interference beams are determined by the birefringence value of the HBF, the polarization state of the PC.

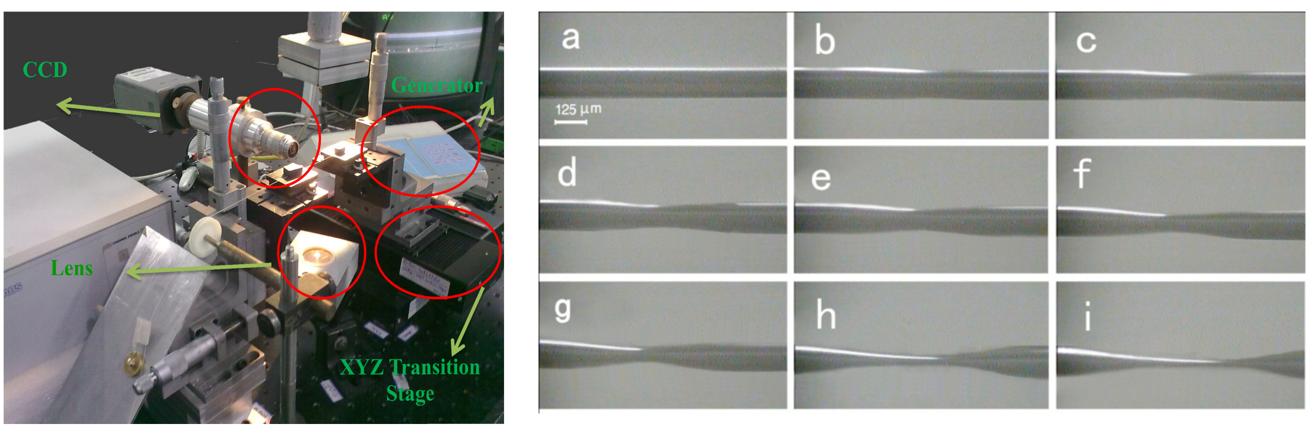

Figure 2 . Image of the tapering system with CO_2 laser (Left), a typical photograph of tapered PANDA fiber in different step (Right)

Figure 2 illustrates the heat pulling system with a CO_2 laser for tapering of the HBF. The geometric characteristic of the fabricated taper depends on the power, number of pulses, beam shape and duty cycle of the CO_2 laser. In our setup, the frequency, duty cycle and number of pulses of CO_2 laser were 430–450 Hz, 35–38% and 65, respectively. A microscope was employed to monitor the tapering process. In this experiment, total length of the HBF was 15.2 cm. Total tapered length and waist diameter of the THBF was about 300 µm and 40 µm, respectively. A typical photograph THBF for different step of tapering is shown in figure 2.

2.2 Experimental results

For measuring the birefringence of the THBF, wavelength spacing of output spectrum of the sensor was measured after every step of tapering. Typical output spectrums and wavelength spacing of different steps of tapering are shown in figure 3(a)-(b), respectively. We traced two wavelength spacing of the spectrum near 1550 nm as depicted in figure 3(a). Calculated birefringences of THBF are shown in figure 4. The results show in the last step of tapering the birefringence of tapered section and total birefringence are -8.02×10^{-2}, and 2.46×10^{-4}, respectively. The negative birefringence of the tapered section can be understood comparing with figure 3(b) and Eq. 2. From obtained spectrum, the initial birefringences at wavelengths of 1535 nm and 1575 nm are 3.98×10^{-4} and 4.01×10^{-4}, respectively. We used these values in Eq.2 for calculating taper birefringence.

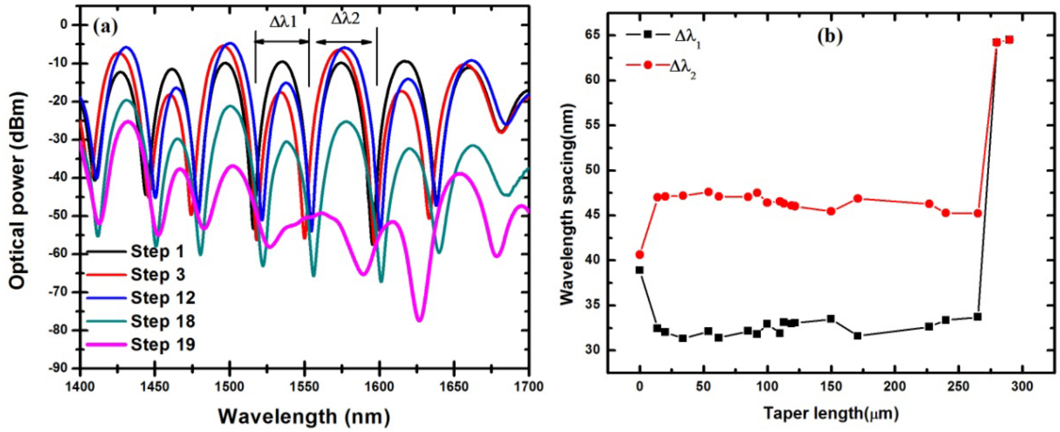

Figure 3. (a) Optical spectrum of the Hi-Bi fiber for step by step tapering, and (b) wavelength spacing in different steps of tapering

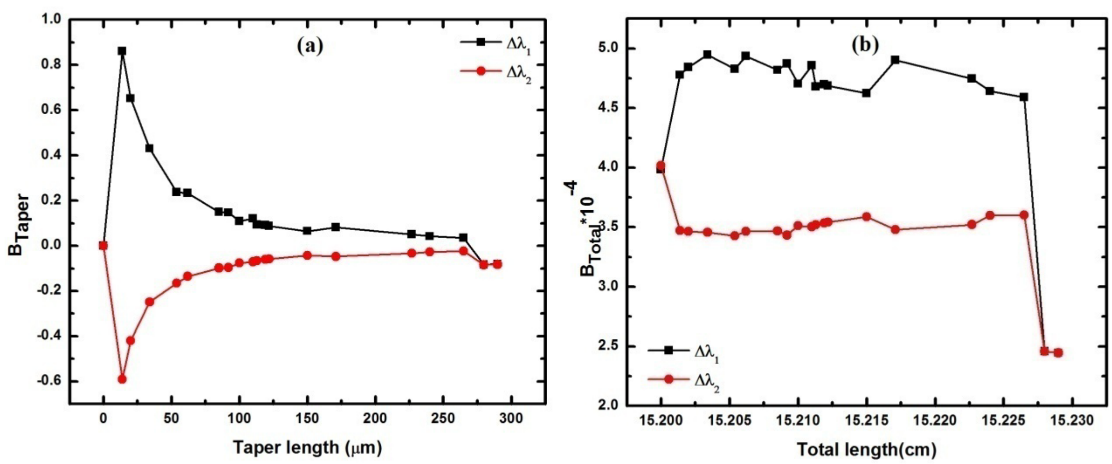

Figure 4. (a) Birefrengnce of the tapered section of HBF, (b) total Birefrengence of the THBF

To calibrate the THBF-FLM sensor for RI measurements, the THBF section was fixed in a holder and immersed into samples of water mixed with different percentages of NaCl. Since the THBF has strong evanescent coupling between the tapered surface and the ambient index overlay, it is expected that the deep wavelengths are changed as the ambient index is changed. The RI sensitivity of the sensor at room temperature in the range 1.3380 and 1.3470 was measured to be 389.85 nm/RIU as it is shown in figure 5(a).

For measuring of temperature sensitivity, the THBF sensor was placed in an oven where the temperature was set from 50°C to 90°C, with a variation lower than 0.1 °C. The obtained result for wavelength versus temperature is shown in figure 5(b). For the case of temperature, a linear dependence is observed with a slope of ~ -1.19nm/°C. The temperature sensitivity of a normal PAND fiber is -1.9 nm/°C [5]. By tapering the PANDA fiber temperature sensitivity 37% was decreased comparing with case normal PANDA fiber.

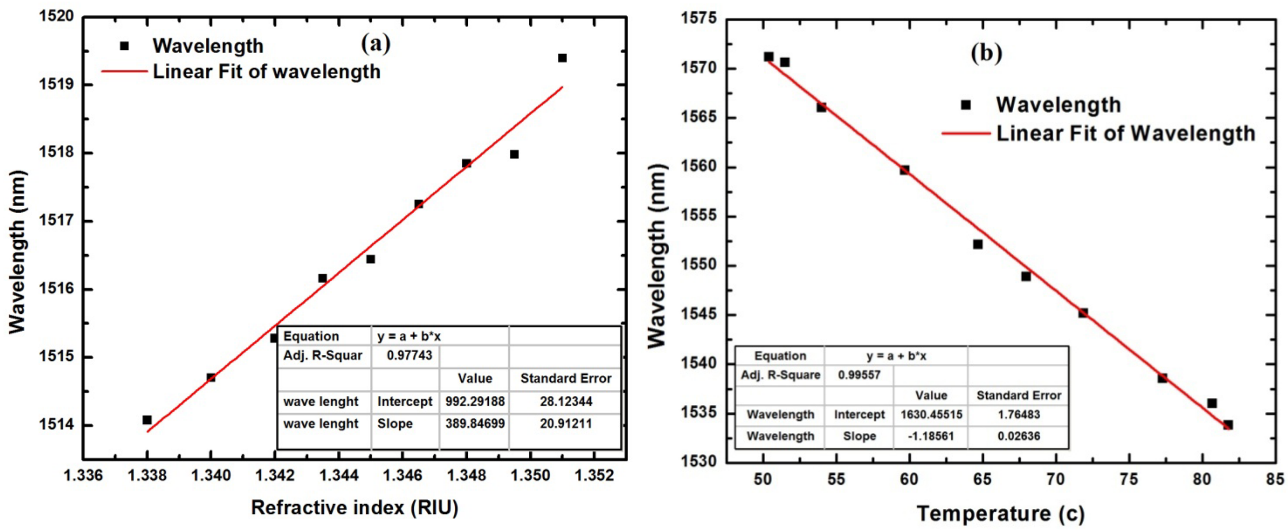

Figure 5. (a) Wavelength versus RI, (b) and temperature for THBF

In addition, the configuration presented here offers simplicity of design and an enhancement of almost an order of magnitude in sensitivity when compared to previous work of a HBF-FLM using chemical etched *D*-type fiber for RI measurement [5-6]. The sensor shows great potential for monitoring chemical and biological parameters in natural environments, provided adequate functionalization of the taper surface is applied.

5. CONCLUSSION

In this paper, a HBF was tapered as adiabatic with heat-pulling method by utilizing a CO_2 laser. By inserting the THBF in FLM setup, total birefringence of the THBF was measured. The results show in the last step of tapering the birefringence of tapered section and total birefringence were -6.05×10^{-2}, and 2.14×10^{-4}, respectively. The RI and temperature sensitivity of the THBF in FLM setup was measured at near wavelength 1550nm. The sensitivity of the proposed FLM interferometer for RI changes in the range from 1.3380 to 1.3470 was measured to be 389.85 nm/RIU. The temperature sensitivity in the range from 50°C to 90 °C was measured to be -1.19nm/°C. From the analysis of experimental results, it is concluded that by tapering RI and temperature sensitivity could be enhanced. In addition, in this particular case, the sensitivity of the TFBF can be controlled and showing great potential in several applications, particularly to monitor chemical and biological parameters in natural environments.

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