An investigation of the polarization dependence of a temperature sensor based on an optical microfiber coupler

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ABSTRACT

Abstract: The dependence on polarization of the performance of a microfiber coupler based temperature sensor is experimentally investigated. The optical microfiber coupler based temperature sensor has a diameter circa 2 μm and can sense temperature in the range from 100 ℃ to 1000 ℃, with an average sensitivity of 18.9 pm/℃. It is shown that different polarization states of the input signal have a significant influence on the proposed temperature sensing accuracy, with a estimated peak error of 63 ℃ at 1000 ℃.

Keywords: Optical microfiber, fiber coupler, temperature sensor, polarization dependence

1. INTRODUCTION

Since being first developed in 2003 [1], optical microfiber and nanowire based photonic devices have been extensively investigated for applications in optical sensing and communication systems [2]. The structure of a tapered fiber microcoupler was first presented in Ref. [3]. Recently, research on an optical microfiber coupler capable of broadband singlemode operation has offered potential new applications in the fields of high performance fiber lasers and optical coherence tomography [4]. Furthermore, the large evanescent field of the microfiber makes the micro-coupling region very sensitive to the surrounding measurands, allowing for the development of a range of fiber optic sensors with high sensitivity and microscale dimensions [1,2].

The polarization dependence of a microfiber has been investigated in [5] and the results suggest new possibilities for polarization discrimination and control within microfiber based photonic devices, such as high-resolution optical fiber sensors, resonators and fiber lasers.

Recently highly sensitive temperature sensors based on a full or half microfiber coupler (MFC) have been presented [6,7]. The maximum sensitivity of such sensors can reach circa 36.6 pm/℃, which is comparable to that achievable with the conventional optical fiber temperature sensors. However the polarization dependence of a microfiber coupler as a function of temperature has not been investigated to date. Experience has shown that polarization dependence is frequently a key limitation of many optical fiber sensors and so an investigation of the polarization dependence of an MFC based sensor is important.

In this paper, we present an investigation of the polarization dependence of a microfiber coupler based temperature sensor, which has a temperature range from 100 ℃ to 1000 ℃ with an average temperature sensitivity of 18.9pm/℃. From the experimental result it can be concluded that the performance of such a microfiber coupler based temperature sensor is sensitive to changes in the polarization state of the input light.

2. FABRICATION OF MICROFIBER COUPLER

The taper drawing system used is based on a ceramic microheater (CMH-7019, NTT-AT). A low-loss MFC was fabricated from two standard telecom optical singlemode fibers (SMF-28, Corning) using the microheater brushing technique [8]. A microfiber coupler comprises two conical transition regions, a central uniform waist region and two input ports (P1 and P2) and two output ports (P3 and P4): light injected from P1 or P2 exits the microfiber coupler from P3 and P4. The lengths of the tapered and uniform waist regions are ~25 mm and ~5 mm respectively [9]. The microfiber

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coupler spectral characterization was carried out using a polarized broadband amplified spontaneous emission source (Fiber Coupled SLD, Thorlabs), with a wavelength range of 1500-1600 nm, connected to P1 and an optical spectrum analyzer (OSA) (86142B, Agilent) connected to P3. The transmission spectrum (at 900 ℃) is presented in Fig. 1 which shows the expected multi-dip spectral pattern for the optical fiber coupler.

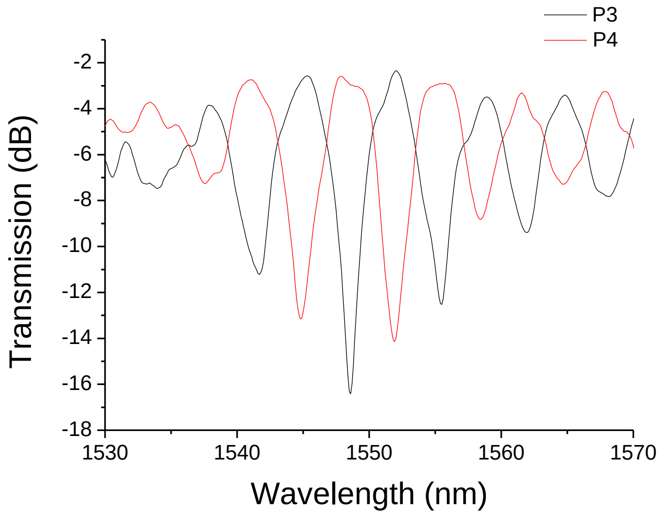


Fig.1. Spectral responses of the two output ports (P3 and P4).

3. MEASUREMENT OF THE TEMPERATURE AND POLARIZATION DEPENDENCIES

To investigate the temperature sensing performance and the effect of polarization for the microfiber coupler, an experimental setup shown in Fig. 2 was used. A manual polarization controller (FB51, Thorlabs) was placed between the broadband source and the microfiber coupler to change the polarization state of the input signal launched into P1. The output signal from P3 was connected to the OSA.

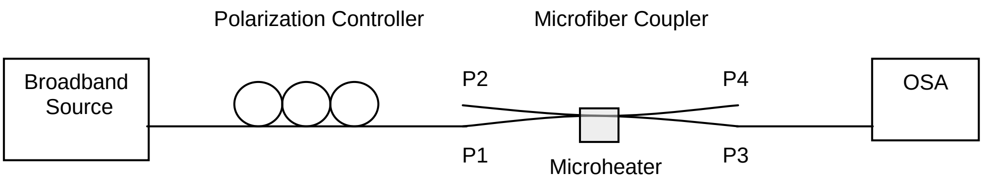
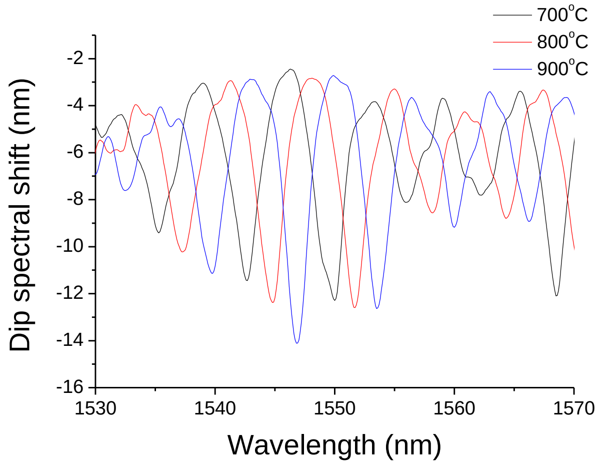
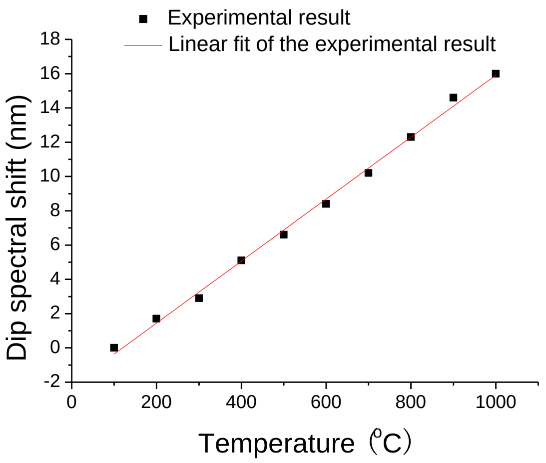


Fig. 2. Schematic diagram of experimental setup

Initially a characterization of the temperature sensing performance of the coupler was carried out without any changes to the polarization state. This temperature characterization was carried using the same microheater used to fabricate the microfiber coupler, as the heater can reach temperatures in excess of 1700 ℃. The uniform section of the taper waist of the microfiber coupler was inserted into the center of the slot in the microheater and transmission spectra were recorded at different temperatures up to 1000 ℃. The microheater temperature was changed by increasing the current flowing into the microheater from 1.1 A to 4.8 A with intervals of circa 0.4 A. The measurements were taken every 5 minutes to ensure a stable temperature had been achieved. Fig. 3 (a) shows some examples of measured spectra for temperatures of 700 ℃, 800 ℃ and 900 ℃. A temperature increase results in a redshift of the spectral response. As an example of the use of the device as sensor, Fig. 3 (b) shows the dip shift with temperature for the dip series starting at 1542.7 nm at 700 ℃, from which it can be determined that the typical temperature sensitivity of this microfiber coupler based sensor is circa 18.9 pm/ ℃ over a temperature range from 100 ℃ to 1000 ℃.





(a) (b)

Fig.3. (a) Spectral response of the microfiber coupler for different temperatures (700 ℃, 800 ℃ and 900 ℃) for the same polarization state (0 °) of the input light. (b) Dip shift versus temperature (from 100 ℃ to 1000 ℃).

The polarization dependence of the microfiber coupler sensor was then measured at each temperature. The polarization state of the input signal was rotated from 0 ° to 90 ° with an interval of 15 ° using a manual polarization controller in order to collect polarization dependent spectral response using the OSA. Fig. 4 shows the dip spectral shifts for different polarization states of the input signal at each temperature. Table 1 shows an analysis of the results of Fig. 4 Setting the 0 ° polarization state as the baseline value (i.e. 0 nm dip shift), the worst case dip shift for each polarization state and the set temperature at which it occurs are listed in Table 1. The effective temperature error for each polarization state is also calculated using the sensitivity of sensor determined from Fig. 3 (b). The results indicate that the microfiber coupler temperature sensor is polarization dependent, which can lead to significant temperature measurement errors.

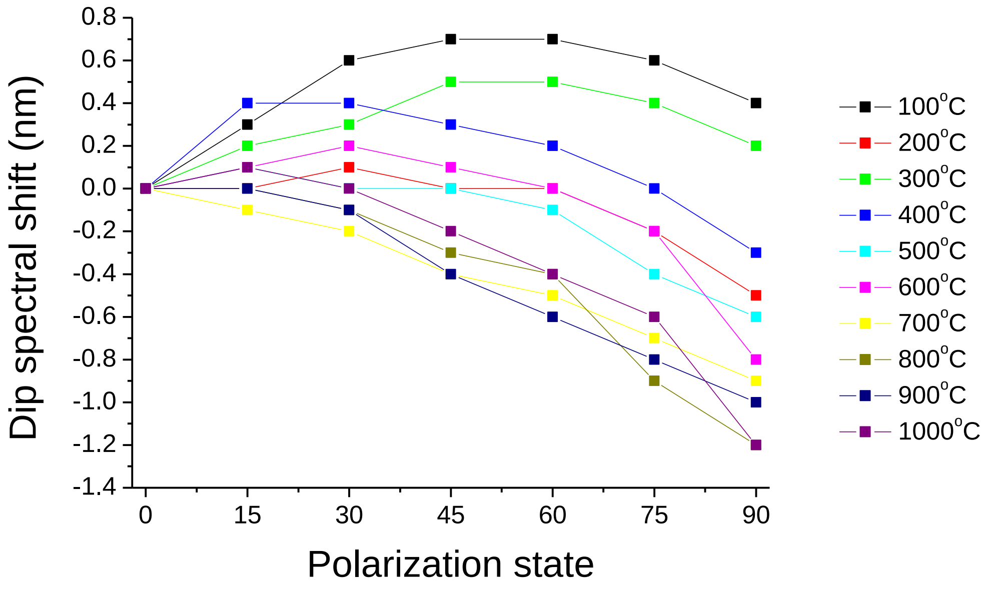


Fig.4. Dip spectral shift versus polarization states at each temperature.

Table 1. Analysis of the result of Fig. 4 showing the estimated polarization induced temperature error.

Polarization state	**Worst case dip shift(nm)**	**Set Temperature at which worst case dip shift occurs (℃)**	**Temperature error (℃)**
15	0.4	400	21.2
30	0.6	100	31.7
45	0.7	100	37.0
60	0.7	100	37.0
75	0.9	800	-47.6
90	1.2	1000	-63.9

4. CONCLUSION

An investigation of polarization dependent performance of a microfiber coupler temperature sensor is presented for a sensor with a sensitivity of 18.9 pm/℃ within a temperature range from 100℃ to 1000℃. Analysis of the measured polarization dependence of the microfiber coupler based temperature sensor indicates that the proposed fiber sensor is sensitive to the different polarization states of the input light and this in turn can result in significant temperature measurement errors. .

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