A high-T, high-Resolution Thermometer based on a Microfiber Coupler Tip

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Abstract: A compact thermometer based on a broadband microfiber coupler tip is demonstrated in this paper. The thermometer can measure a broad temperature range from room temperature to 1283ºC. This is the highest temperature measured with a silica optical fiber device. An average sensitivity of 11.96pm/ºC was achieved for a coupler tip diameter of ~3 µm.
OCIS codes: (060.2370) Fiber optics sensors; (060.1810) Buffers, couplers, routers, switches, and multiplexers; (060.2340) Fiber optics components; (230.1150) All-optical devices

1. Introduction

Fused fiber couplers have found several applications in sensing including, amongst others, pressure [1], ultrasound [2] and temperature [3]. Temperature measurement is one of the most important parameters for many applications, such as in oil fields, electric power systems and tunnel fire alarms. Fiber Bragg gratings (FBGs) [4] are the most successful device used to monitor temperature with silica optical fibers; yet, they have been used only for temperatures up to 1000°C and also exhibit strong limitations for high resolution measurements because of their big size.

In this paper, a compact thermometer based on a microfiber coupler (MFC) tip is presented. In the coupling region of a MFC [5], optical paths depend both on the coupling region length and its refractive index; since both depend on the surrounding environment, and in particular on its temperature, the MFC can be used as a highly sensitive thermometer.

In this work, a MFC was cut into two equal parts at the center of the minimum waist region and the microfiber coupler tip (MFCT) was used as sensor head. Since this component is made by silica, the measuring range can potentially reach very high temperatures in excess of 1200ºC. Its small size (~3µm tip diameter), all fiberized connection and low-cost offer great potential for high-temperature sensing, especially in confined areas.

2. Device manufacture

Figure 1(a) shows the schematic of the bi-conical MFCT. MFCT comprises a conical transition region, a uniform tip with small diameter and two input/output ports: light launched from port P_1 is partially reflected by the flat surface of the tip and can be measured at port P_2. A low-loss MFC was fabricated from two standard telecom optical fibers using the microheater brushing technique [6]. Then the low-loss MFC was cleaved into two MFCT. Fig. 1(b) shows the scanning electron microscope (SEM) image of the MFCT with diameter ~3µm and ~2mm uniform waist region.

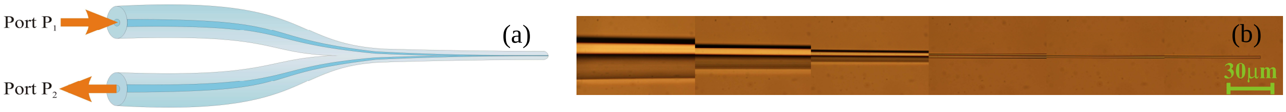
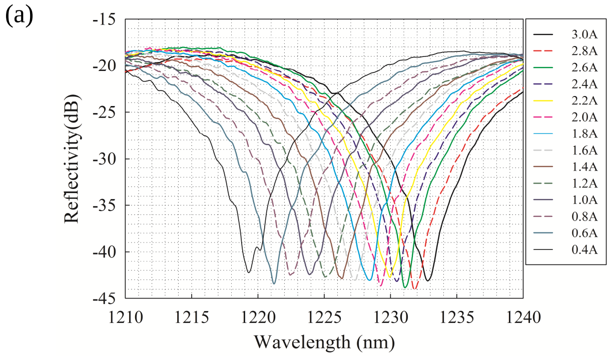


Fig. 1. (a) Schematic of a bi-conical microfiber coupler tip (MFCT); (b) SEM images of the MFCT with diameter ~3µm and 2mm uniform waist region.

3. Characterization

The MFCT spectral characterization was carried out with a supercontinuum (SC) source (Fianium Ltd, Southampton, U.K.), which delivers light over the wavelengths range 450-1800nm. Spectrum was recorded in port P_2 by an optical spectrum analyzer (OSA) (AQ6317, Yokogawa, Japan). The microheater (NTT-AT, Tokyo, Japan) used to fabricate the MFC can reach temperatures in excess of 1700ºC, thus it can be used in the sensor characterization. The MFCT was inserted to the microheater center and reflection spectra were measured for different temperatures. The measurement was taken every 15mins to ensure a good temperature stability. Fig. 2(a) shows the spectral shift of the peak at 1219 nm for increasing currents from 0.4A to 2.8A in steps of 0.2 A (i.e. the corresponding temperature is from ~247ºC to ~1283ºC). When the driver current is increased, the temperature increases and the peak redshifts to long wavelengths. An average S~11.96 pm/ºC was achieved, comparable to the value obtained for FBG thermometers at lower temperature [7]. To increase the sensor accuracy, the spectrum was fit with a Laurentian function and its center was used as reference. The sensor resolution was estimated to be ~0.836ºC for an OSA resolution of 0.01nm.

The MFCT thermometer repeatability was measured recording spectra for increasing and decreasing temperature with an interval of one hour. The shift with the temperature is shown in Fig. 2(b): the two curves fit very well showing that the MFCT thermometer has good repeatability.



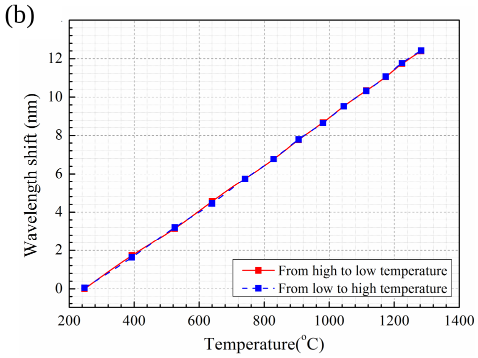
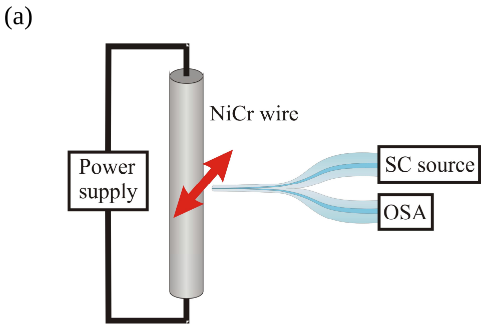


Fig. 2. (a) The reflection spectra of the peak at 1219nm when the driver current increases every 0.2A; (b) The wavelength shift dependence on the temperature. The red solid curve and the blue dash curve report measurements for decreasing and increasing temperatures, respectively.

In order to demonstrate that the sensor has high 2D spatial resolution, temperature measurements were carried out (Fig. 3(a)) on a ~500µm diameter Nickel-Chromium (Ni-Cr) wire heated by Ohm effect. Spectra were recorded every 125 µm at a distance of ~250 µm from the Ni-Cr surface along the tangential direction: the peak shift variation with the MFCT position is presented in Fig. 3(b), with the origin taken as the central axis of the wire. A sharp peak with a full width at half maximum of ~1150 µm was observed. A wavelength shift of 1.19 nm was recorded at the wire center, corresponding to a temperature difference of ~99ºC.



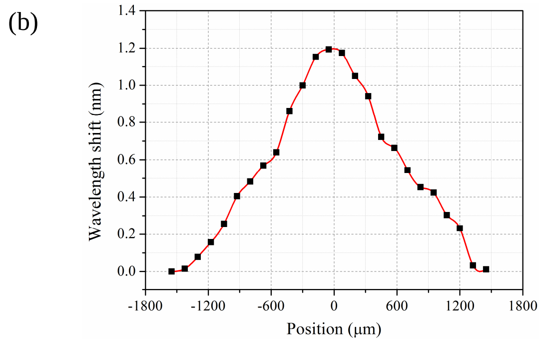


Fig. 3. (a) Experimental set-up used to demonstrate the MFCT 2D spatial resolution; (b) sensor response when the MFCT was scanned along the tangential direction of the Ni-Cr wire.

4. Conclusion

In summary, a compact temperature sensor which uses a bi-conical MFCT for high-temperature sensing with high 2D spatial resolution has been demonstrated. MFCT offers several advantages, most notably compactness (few µm in diameter), high temperature measurement capabilities, high sensitivity, high spatial resolution, easy connection with other fiberized optical components, simple fabrication and low cost.

5. References

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