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Bent SMS Fiber Structure for Temperature Measurement

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Abstract: We have proposed a temperature sensor fabricated using a bent SMS fiber structure. Our experimental results show, that by comparison to a sensor based on a straight SMS fiber structure, this temperature sensor has a much higher sensitivity of 31.97 pm/°C over a temperature range from 20 to 80 °C based on the measurement of the mean 3 dB wavelength shift and offers a resolution of 0.1 °C for temperature range from 45 to 80 °C when demodulated by a simple ratiometric interrogation technique.

Index Terms—Singlemode-multimode-singlemode fiber, optical sensing

Introduction:

Optical fibre based temperature sensors have been studied extensively [1-5]. Temperature sensing can be implemented by in a number of ways, for example a fibre Bragg grating (FBG) [1-3], or macro-bend singlemode fibre (SMF) [4], or a singlemode-multomode-singlemode (SMS) fibre structure [5]. The underlying principle of sensors based on SMS fibre structures is the multimode interference between modes excited in the multimode fibre (MMF) along the MMF length. Since the refractive index and dimensions of both the fiber core and cladding are temperature sensitive, the modes excited in the MMF will change as temperature changes, and hence the output of the SMS fibre structure also changes. This change will introduce a wavelength shift of the SMS fibre structure spectral response and thus temperature information can be extracted by monitoring the wavelength shift. A recent investigation shows that for a particular SMS fibre structure the temperature sensitivity is 8.7 pm/°C [6], comparable to that of a typical FBG. This result is based on a straight SMS fibre structure. If the MMF section is bent, the modes excited in the MMF will undergo significant changes and the SMS transmission spectrum will change accordingly. In particular in our experimental investigations it is found that the temperature dependence of the spectrum increases. Our investigation shows for the first time that a bent SMS fibre structure used as a temperature sensor has a much higher temperature sensitivity of 32 pm/°C, significantly higher than that of a straight SMS structure or a FBG.

Experiment:

An experimental setup to utilise a bent SMS fibre structure for temperature sensing is shown in figure 1.

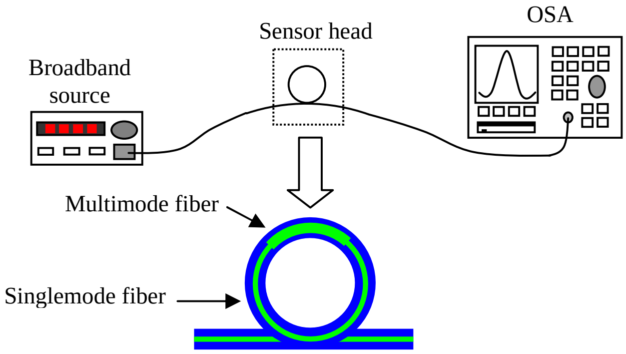

Fig. 1 Schematic experimental setup

The single- and multimode fibers used in our experiments were SMF28 and AFS105/125Y respectively. The two ends of the MMF are fusion spliced to two SMF 28 single mode fibers and the SMS fiber structure is bent with a diameter of 56.86 mm. The length of the MMF is 42.1 mm. The MMF portion of the SMS fiber structure is temperature controlled by a Peltier cooler. It is noted that the relationship between sensitivity and bend radius is complex and that the bend radius used here was selected experimentally to achieve a high sensitivity. It is accepted that further investigation of the relationship between bend radius and sensitivity is needed to achieve the highest possible sensitivity.

Experimental investigations were carried out for the proposed system based on a bent SMS fiber structure. The measured spectral response vs. temperature is shown in figure 2.

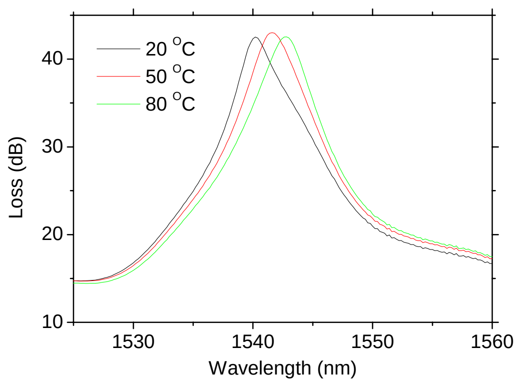

Fig. 2 Spectral response vs. temperature of the bent SMS structure

Figure 2 shows that as temperature increases the central wavelength moves to longer wavelength. Figure 3 shows the mean 3 dB wavelength measured by the OSA vs. temperature at 5 ºC intervals for a temperature range from 20 to 80 ºC. Mean 3 dB wavelength is chosen instead of peak wavelength for measurement as it is known to be a more reliable OSA measurement.

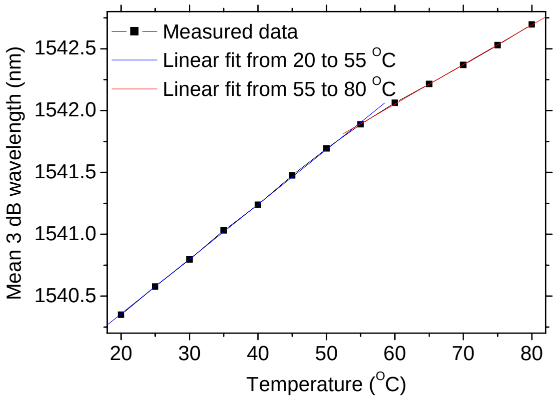

Fig. 3 Measured mean 3 dB wavelength vs. temperature

Figure 3 shows that as temperature increases, the mean 3 dB wavelength increases monotonically. A linear fit is applied to the measured data in the temperature range from 20 to 55 ºC and from 55 to 80 ºC separately, both data sets show a good linearity, demonstrated by a linear regression value $R^2 = 0.99966$. The fitted function is shown below:

$$\lambda = \begin{cases} 1539.47096 + 0.04426T & 20 \le T \le 54.04 \\ 1540.1351 + 0.03197T & 54.04 \le T \le 80 \end{cases} \qquad (1)$$

Eq. (1) shows that the bent SMS sensor has temperature sensitivity of 44.26 pm/°C in the temperature range from 20 to 54.04 °C and 31.97 pm/°C in the temperature range from 54.04 to 80 °C respectively, which is much greater than that of the straight SMS temperature sensor (8.7 pm/°C). It should be noted that the 20-80 ºC temperature range in our experiment was limited by the Peltier cooler used and the proposed sensor has the potential to be used over a wider temperature range.

The demodulation method above was based on measuring the temperature induced wavelength shift by using an optical spectrum analyzer (OSA), which is complex and expensive. A simple and reliable alternative interrogation technique is to use a ratiometric system to demodulate the temperature sensor [4-6]. The schematic diagram of the ratiometric interrogation system is shown in figure 4.

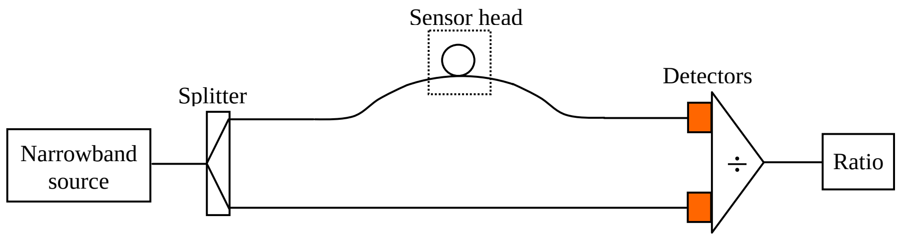

Fig. 4 Schematic diagram for a bent SMS temperature sensor in a ratiometric system

Figure 4 shows a system where a narrowband optical signal is split into two arms: one goes to the photodiode directly acting as a reference arm to compensate for the source power variations; the other is connected to the temperature sensor and detected by a photodiode as a signal arm. Since the signal arm is temperature dependant, the temperature information can be extracted simply by measuring the power ratio of the two arms. An experiment was carried out by measuring the ratio response at 5 °C intervals for a temperature range from 20 to 80 °C. The input narrowband wavelength is 1540.5 nm and the experimental result is shown in figure 5.

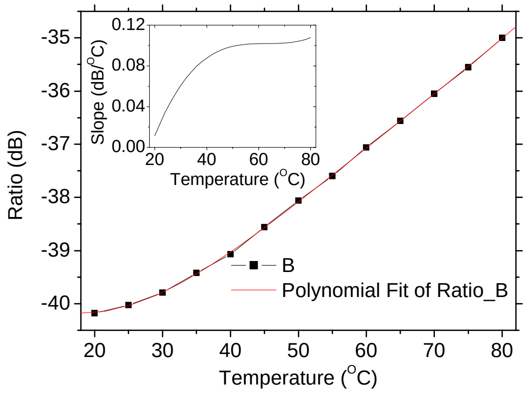

Fig. 5 Measured ratio vs. temperature

Figure 5 shows that as temperature increases, the measured ratio increases monotonically as a fitted polynomial function:

$$y = -38.70954 - 0.18108T + 0.00671T^2 - 7.08467\times10^{-5}T^3 + 2.80749\times10^{-7}T^4 \qquad (2)$$

The inset graph in figure 5 is the slope of the fitted function. It shows that the slope is higher than 0.1 dB/°C in the temperature range from 45 to 80 °C, which is also greater than the 0.051 dB/°C – corresponding value for a straight SMS temperature sensor. Assuming the accuracy of a typical commercial optical power meter as 0.01 dB, the temperature sensor will have resolution of 0.1 °C in the temperature range from 45 to 80 °C.

Finally it is noted that since it is difficult to achieve a repeatable mode filling of a multimode structure, the performance of the sensor will vary from unit to unit and that calibration of each fabricated sensor will be required.

Conclusion:

In conclusion we have reported a bent SMS temperature sensor with improved sensitivity compared to a similar sensor based on a straight SMS fiber structure. The sensor can be demodulated either by an OSA with a sensitivity of 31.97 pm/°C in the temperature range from 20 to 80 °C or by a ratiometric interrogation system with a temperature resolution of 0.1 °C in the temperature range from 45 to 80 °C.

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