A practical temperature sensor with high sensitivity utilizing a fiber loop mirror with a long-period grating in a photonic crystal fiber

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Abstract A practical temperature sensor by using a highly birefringent fiber loop mirror concatenated with a long-period grating written in a photonic crystal fiber (PCF) is proposed and the sensitivity of the sensor is about-0.4872 dB/℃.

1. Introduction

Fiber loop mirrors (FLMs) have been demonstrated for a number of applications, for example wavelength filters and sensors [1–2]. In a FLM, two interfering waves counter-propagate through the same fiber, and are exposed to the same environment. This makes it less sensitive to environmental disturbance. A FLM made of highly birefringent fiber (HiBi-FLM) has several advantages, including input polarization independence and high extinction ratio, in addition to the good environmental stability and low cost [3,4]. Usually, sensitivity of the sensors based on HiBi-FLM are high. For example, a temperature sensor based on a HiBi-FLM has showed a sensitivity of 0.94 nm/℃ which is ~94 times greater than that of a fiber Bragg grating [2]. However, most HiBi-FLM sensors are based on monitoring the resonant wavelength variation of FLMs [5]. Since an expensive optical spectrum analyzer (OSA) is needed, the system is relatively high cost.

In this letter we present a practical sensor with high sensitivity for the temperature measurement by using a HiBi-FLM concatenated with a long-period grating written in photonic crystal fibers (PCF-LPG). For the sensing principle, only the HiBi-FLM acts as a sensor head, while the PCF-LPG serves as a filter to provide wavelength dependent optical power transmission [6,7]. The bandpass filter is used to provide a narrow band light source, thus only one of transmission peaks of the HiBi-FLM is located within a negative linear region of the LPG's transmission spectrum. By utilizing the stable filtering function of the LPG in PCF, the resonant wavelength variation of the FLM with temperature is transferred effectively to the intensity variation of the output light. When the optical power of the output is monitored, the temperature applied on the FLM will be deduced. Since only an optical power meter is sufficient to detect temperature variation in the configuration, an expensive OSA would not be needed. Furthermore, only the FLM is temperature sensitive, the whole temperature sensor system can be placed in one compact package. Thus it is very feasible to monitor the temperature variation in a relatively cheap manner.

2. Experimental setup

Fig.1 shows the experimental setup. The configuration of the proposed sensor includes a bandpass filter, a HiBi-FLM, and a LPG in PCF. A narrowband light source launches the HiBi-FLM via a 3 dB coupler. The transmitted light from the HiBi-FLM then enters the temperature-insensitive LPG written in PCF. At the output, light spectrum is monitored using an OSA with a spectral resolution of 0.02 nm or the output power is measured by an optical power meter (OPM) with a resolution of 0.01 dB.

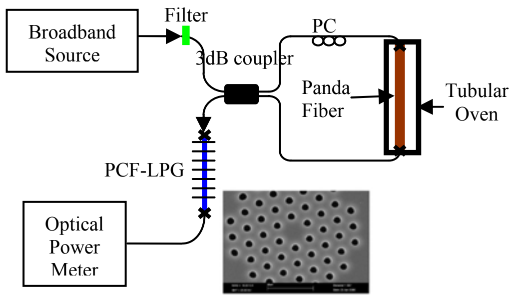

Fig. 1. Experimental setup of a FLM concatenated with a LPG in PCF. Red line, panda fiber; blue line, PCF; black line, SMF; Green line, MDM filter. Inset, micrograph of the PCF.

The bandpass filter with a central wavelength of 1545 nm and a full width of 12 nm is made of Metal-Dielectric-Metal (MDM), which is used to provide a narrow band light source. The HiBi-FLM is formed with a 3dB coupler, a 30.5cm PANDA polarization maintaining fiber (PMF), and a polarization controller (PC). In the experiment, the whole of PANDA PMF is used as a sensing element and placed in a tubular oven, which permits temperature resolution with as small as 0.1℃. The PANDA PMF which is provided by the TianJin CECT 46 Research Center of China has a measured group birefringence at 1550 nm.

The PCF used in our experiments is an endless-single-mode PCF (ESM-PCF) purchased from Crystal Fiber A/S, and the cross-sectional scanning electron micrograph is also shown in Fig. 1. A pulsed CO_2 laser is used to fabricate the LPG, and the details have been described previously [9]. The LPG inscribed has 40 periods and the period is about 467 μm. The total length of the PCF is 5 cm, and both ends of the PCF are fusion spliced to single-mode fiber by using a regular splicing machine. The loss of each splice is about 0.5 dB.

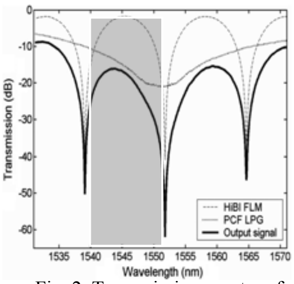

Fig. 2. Transmission spectra of the FLM and of the LPG in PCF and the output signal. Gray region is practical transmission spectra of the sensor

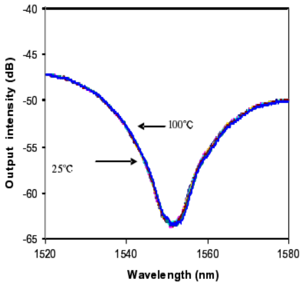

Fig. 3 Transmission spectra of the PCF-LPG at the different temperature.

3. Experiment and results

Fig.2 shows transmission spectrum of the PCF-LPG, the HiBi-FLM, and the output signal. The spectrum measurements are performed using a broadband source. The transmission spectra are observed with an OSA with a resolution of 0.02 nm.

The transmission dip of the LPG in the PCF is about 1552.45 nm which is due to the fundamental core mode coupling to one cladding mode. The dip at the wavelength 1552.45 nm is nearly -20 dB. The wavelength range in which a negative slope in the transmission intensity occurs is from 1520 nm to 1552.45 nm, i.e. about 32 nm. Meanwhile, the wavelength range with a positive slope is from 1552.45 to 1580 nm, i.e. about 28 nm. In order to show that the PCF-LPG is temperature-insensitive, the PCF-LPG is placed in a temperature chamber whose temperature is controlled in the range of 25℃ to 100℃. As shown in Fig.3, when the temperature within the chamber rose from 25℃ to 100℃, the resonant wavelengths remain stable. This means that the stable interrogation of the FLM temperature sensor will be realized by using the temperature-insensitive of the LPG in the PCF.

Fig.2 also shows the transmission spectrum of the HiBi-FLM. The wavelength spacing between the transmission peaks of the HiBi-FLM is about 13 nm at 1545 nm. This value is determined considering by adjusting the state of the PC, only one spectral peak of the FLM is located in a negative slope of linear regions with the LPG. As shown the gray region in the Fig.2, when the bandpass filter with a width 12 nm and a center at 1545 nm is used, the power of the output light will be changed proportionally with transmission peak shift of the HiBi-FLM in a certain range.

To obtain the temperature sensitivity of the sensor system, the whole PMF is placed in a tubular oven, which permits temperature resolution with as small as 0.1℃. When the temperature is increased from 40℃ to 60℃, the transmission spectra of the FLM will shift, and the intensity of the output changes in accordance with the transmission curve of the LPG. As the transmission wavelength of the FLM shifts to shorter wavelength, the output power becomes larger. Fig. 4 shows the relationship of the output intensity of the LPG with the

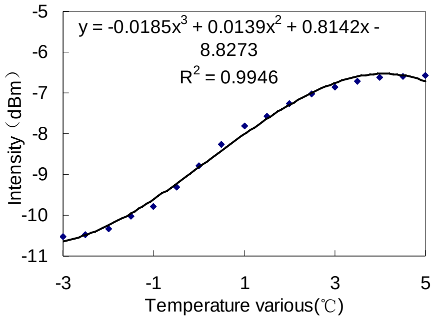

Fig.4. The relationship of the output power and temperature various.

temperature on the FLM, and this relationship is virtually proportional for temperature from 47℃ to 55℃. In this temperature range (8℃), the change in the transmission wavelength of the FLM is 6.54 nm, and the intensity change of the output power is 3.9493dBm. The sensitivity of the proposed FLM temperature sensor is ~0.4937dBm/℃. When using an OPM with the resolution of 0.01dBm, the temperature resolution is obtained 0.02℃.

4. Conclusion

In conclusion, we present a practical sensor with high sensitivity for the temperature measurement by using a HiBi-FLM concatenated with PCF-LPG. This system is simple and works accurately in environments in which the temperature can change in a wide range. Since, only FLM head is temperature sensitive, the whole temperature sensor system can be placed in one compact package.

Acknowledgments

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