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Multi-functional optical fiber sensor system based on a dense wavelength division multiplexer*

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We propose a novel and efficient multi-functional optical fiber sensor system based on a dense wavelength division multiplexer (DWDM). This system consists of an optical fiber temperature sensor, an optical fiber strain sensor, and a 48-channel DWDM. This system can monitor temperature and strain changes at the same time. The ranges of these two sensors are from −20 °C to 100 °C and from −1000 $\mu\varepsilon$ to 2000 $\mu\varepsilon$, respectively. The sensitivities of the temperature sensor and strain sensor are 0.03572 nm/°C and 0.03808 nm/N, respectively. With the aid of a broadband source and spectrometer, different kinds and ranges of parameters in the environment can be monitored by using suitable sensors.

Keywords: dense wavelength division multiplexer (DWDM), planar lightwave circuit, multi-functional sensor, optical fiber sensor system

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1. Introduction

Owing to the advantages of their low cost, high sensitivity, electromagnetic immunity, and easy fabrication, optical fiber grating sensors have been widely invested in and used in many fields, including medicine,[1] robotics,[2] and industrial monitoring, where there is assessment of parameters such as force,[3] temperature,[4] liquid level,[5] and vibration[6] in both point and quasi-distributed measurements.[7] However, most of these optical fiber sensors hardly realize functional integration if these parameters might ever be similar.[8,9] In the meantime, optical networks have been invested in because of the rapid increase of data traffic in communication in the last two decades. Dense wavelength division multiplexers (DWDMs)[10–12] as well as coarse wavelength division multiplexers (CWDMs)[13–15] have been widely researched around the world, making multi-channel sensors possible. In order to make the best use of instruments and sensors, the multi-channel sensor system[16] and control system[17] have been proposed recently. Nevertheless, these systems are still limited in the same parameter. Optical multi-functional integration is becoming a compelling path towards delivering optical modules with enhanced functionality at a reduced cost.[18]

In this paper, we demonstrate a multi-functional optical fiber system based on a DWDM. The system consists of an optical fiber temperature sensor, an optical fiber strain sensor, and a 48-channel DWDM. A broadband source is divided into 48 parts with a wavelength spacing of 0.8 nm. Two different kinds of optical fiber sensors are connected with 2 channels of this DWDM. A spectrometer is used to detect the spectrum from the output ports of these two sensors. We find spectral shifts according to the temperature change and the strain change. Then we can obtain the temperature and strain in this situation. The sensor system demonstrated can monitor two parameters simultaneously and realize the functional integration, which can be used to monitor remote environmental changes through an optical fiber network. Since a multi-functional monolithic device is compact and urgently needed,[19] further work will include integrating different functions on one chip.

2. Experiments and results

Figure 1 shows the optical configuration of the proposed multi-functional optical fiber sensor system. A broadband source as a light source is incident on a DWDM. The DWDM splits the light into 48 parts with different central wavelengths with a wavelength spacing of 0.8 nm. As shown in Fig. 1, the outputs of the DWDM are delivered into different sensors which can monitor different ranges or different parameters. In this work, we selected two different optical fiber sensors based on Bragg grating theory. Under the effect of the fiber sensor, the specific wavelength of the spectrum from the DWDM is depressed, which is used to monitor the measuring parameter. For our design, we chose two channels C17 and C19 from the 48 channels according to our optical fiber

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sensors' working ranges, so that we can monitor different environmental changes at the same time. For the temperature sensor part of the system, the interference wavelength will be changed with the temperature variation, and the relationship can be described as[20]

$$\Delta T = K_{\mathrm{t}} \times (\lambda - \lambda_0), \tag{1}$$

where ΔT is the relative temperature change and K_{t} is the coefficient of temperature.

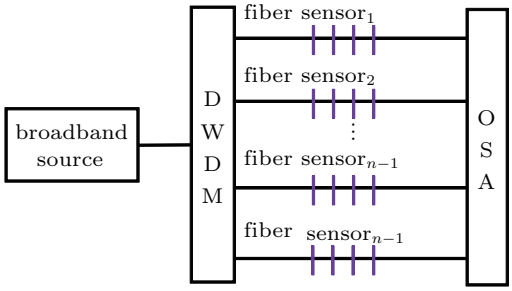


Fig. 1. Optical configuration of the multi-functional optical fiber sensor system.

On the other hand, the strain sensor will also be affected by temperature disturbance. In our experiment, we try our best to keep the room temperature constant so that we can ignore the effects of temperature change and then monitor the strain change applied to the sensor. The interference wavelength will be changed with the strain variation, and the relationship can be described as[20]

$$\Delta E = K_{\mathrm{f}} \times (\lambda - \lambda_0 - K_{\mathrm{t0}} \Delta T), \tag{2}$$

where ΔE is the relative strain change, K_{f} is the coefficient of strain, and K_{t0} is the temperature rectifying coefficient.

In order to verify our design, we built the multi-functional optical fiber sensor system and measured the relative parameters. Figure 2 shows a picture of the multi-functional optical fiber sensor system. The DWDM has 48 channels with central wavelengths from 1526.408 nm to 1563.824 nm, each with a 0.8 nm bandwidth. In our experiment, we used channels C17 and C19 according to the central wavelengths of the selected optical fiber sensors as an example to verify our sensor system. With the aid of a broadband source (SC-5, Yangtze Soton Laser) and an optical spectrum analyzer (OSA, MS9740 A, Anritsu), we could measure the spectrum shifts and calculate the sensitivities. The light from the broadband source is coupled into the input port of the DWDM via a single mode fiber. The output light from C17 and C19 of the DWDM is separately coupled into the two optical fiber sensors with the single mode fibers and FC/APC connectors. We firstly measured the output spectrum of the DWDM from C21 to C17, as shown in Fig. 3. The central wavelengths of channels C17 and C19 are 1563.914 nm and 1563.095 nm, respectively.

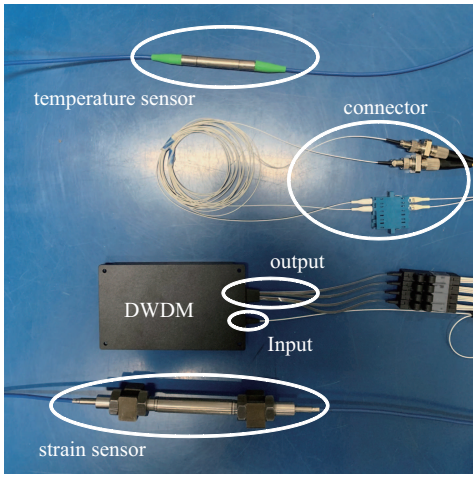


Fig. 2. Picture of the multi-functional optical fiber sensor system.

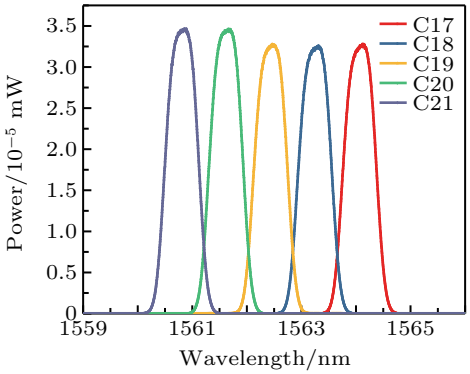


Fig. 3. The spectrum of the DWDM from C21 to C17.

Next, we characterized the function of the optical fiber strain sensor. Because the strain or the stress change can be characterized by forces, we applied different forces to the sensor and obtained a series of spectra, as shown in Fig. 4(a). It is obvious that, as the force applied on the sensor was increased gradually, a significant wavelength shift of the interference dips was observed. Figure 4(b) summarizes the relationship between the force and the interference wavelength shift. The fitting curves can be described as $y = -0.03808x + 1562.66$, and a high fitting degree of 0.98763 is obtained. Therefore, it can be calculated that the sensitivity of this part is 0.03808 nm/N.

Then, we characterized the function of the optical fiber temperature sensor. We applied different temperatures to the sensor and obtained a series of spectra, as shown in Fig. 5(a). It is obvious that, as the temperature applied to the sensor was increased gradually from 41 °C to 45.1 °C, a significant wavelength shift of the interference dips was observed. Figure 5(b) summarizes the relationship between the temperature and the interference wavelength shift. The fitting curves can be described as $y = -0.03572x + 1562.61$, and a high fitting degree of 0.98381 is obtained. Therefore, it can be calculated that the sensitivity of this part is 0.03572 nm/°C.

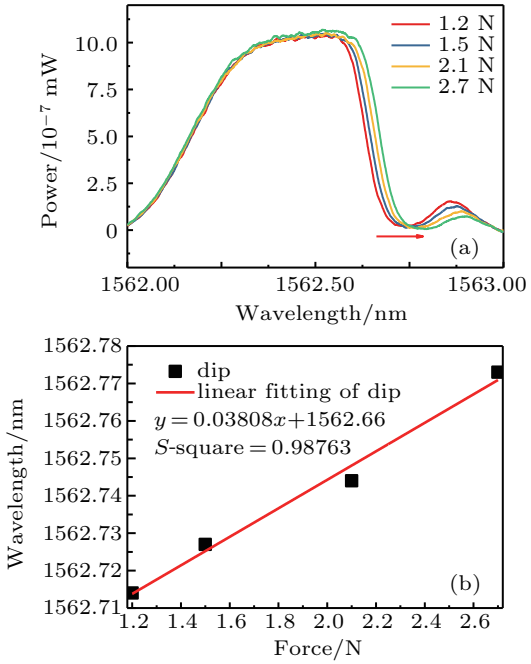


Fig. 4. (a) The measured spectrum of the strain sensor. (b) The relationship between the force and the interference dips.

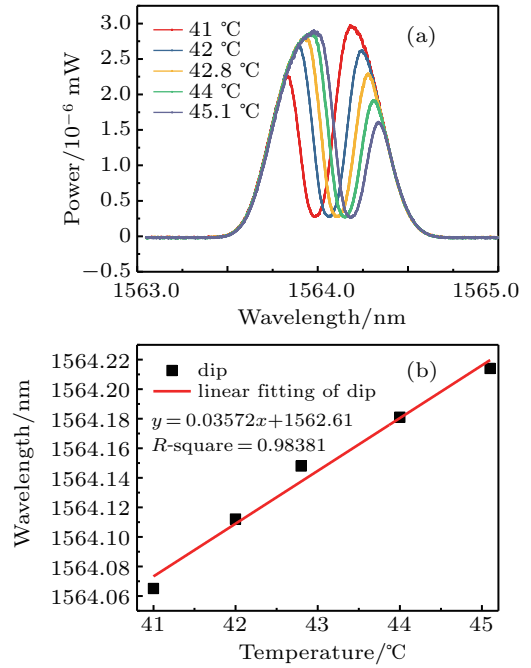


Fig. 5. (a) The measured spectrum of the temperature sensor. (b) The relationship between the temperature and the interference dips.

According to the above experiments and analysis, we have confirmed that the proposed system has two different functions that can monitor strain and temperature changes. The main advantage of the proposed system is a simple configuration to extend the measurement channels with a single optical source and a spectrometer. With different sensors, we can obtain different parameters of the environment at the same time. Moreover, the sensors in this system can be placed at different areas through an optical fiber network. Therefore, we can realize the function of a remote monitor using this system. Although the resolution and stability are not sufficient to be at nanometer levels, in fact, the performances of the system can be improved with the development of the optical sources and optical fiber sensors.

3. Conclusion

We have proposed a novel and efficient multi-functional optical fiber sensor system based on a dense wavelength division multiplexer. The system consists of an optical fiber temperature sensor, an optical fiber strain sensor, and a 48-channel DWDM. This system can monitor temperature and strain changes at the same time. The ranges of these two sensors are from -20 °C to 100 °C and from -1000 $\mu\varepsilon$ to 2000 $\mu\varepsilon$. The sensitivities of the temperature sensor and strain sensor are 0.03572 nm/°C and 0.03808 nm/N, respectively. With the aid of a broadband source and spectrometer, different kinds and ranges of parameters in the environment can be monitored by using suitable sensors.

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