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Fiber-Optic Displacement Sensor Based on the DBR Fiber Laser

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Abstract: The fiber-optic displacement sensor based on the distributed Bragg reflector fiber laser is proposed, that is, the fiber laser cavity is attached to the measured object, when the measured object is stretched or contracted, and the length of the fiber laser cavity is also stretched or contracted accordingly. In view of the nonlinearity of the fiber-optic displacement sensor, the calibration based on piezoelectric ceramics is applied to improve the linearity of the displacement sensor. Experiment results show that the fiber-optic displacement sensor has a linear response with the nominal working distance of 90 μm.

Keywords: DBR fiber laser, fiber-optic displacement sensor, fiber laser cavity, FBG

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1. Introduction

The displacement sensors are essential instruments in metrology [1–3]. Especially, the fiber-optic displacement sensors are more attractive because they have many advantages, such as light weight, compact size, good flexibility, electrical isolation, and capability of multiplexing [4]. Now all kinds of fiber-optic displacement sensors have been reported. Most of them are based on intensity reflection or intensity modulation. The drawbacks of the intensity-based displacement sensors include nonlinear response, low accuracy, poor stability, and short measurement range. The distributed Bragg reflector (DBR) fiber laser sensors have the advantages of providing high signal-to-noise ratios and potentially very high resolution. In the last two decades, extensive researches have been investigated for high performance DBR fiber laser sensor applications, including the measurement of transverse pressure [5, 6], lateral force [7, 8] and torsion, and high-frequency ultrasound detection [9, 10].

In this paper, the fiber-optic displacement sensor based on the DBR fiber laser is proposed. That is, the fiber laser cavity is attached to the measured object, which constitutes a fiber-optic displacement sensor. When the object is stretched or contracted, and the length of the fiber laser cavity is also stretched or contracted accordingly, so the curve of the wavelength shift of the fiber laser is proportional to the changing displacement. In view of the nonlinear problem of the fiber-optic displacement sensor, the piezoelectric ceramics (PZT) with closed-loop operation is applied to calibrate the fiber-optic displacement sensors, and it shows a good effect.

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2. DBR fiber laser fabrication

The DBR fiber laser used in the experiment consisted of a pair of wavelength-matched fiber Bragg gratings (FBGs) written in an erbium-doped fiber. Figure 1 shows the schematic diagram of the short-cavity DBR fiber laser and its inscription process. The DBR fiber laser was fabricated by directly photowriting two wavelength-matched Bragg gratings into the active fiber. The ultraviolet (UV) light source was 193-nm excimer laser, and it induced the index change by the two-photon excitation process. The beam scanning technique was used, in which the phase mask and the fiber were fixed, while the laser beam was scanned along the fiber. The two gratings were written with the same beam scanning speed so that they had the same index change and the same central wavelength.

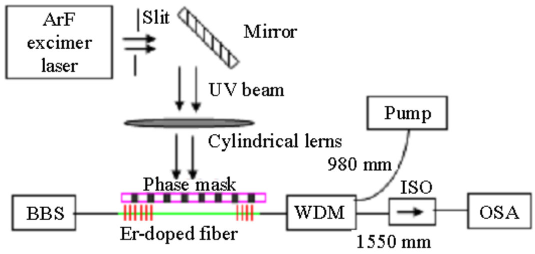

Fig. 1 Schematic diagram and inscription process of the DBR fiber laser.

We first wrote the high reflectivity grating, and the grating transmission spectrum was monitored with a broadband source (BBS) and an optical spectrum analyzer (OSA). A 6-mm-length high reflectivity grating with reflectivity around 40 dB was easily fabricated with our inscription system. We then wrote the low reflectivity grating using the same scanning speed and the same laser settings. During the inscription of the low reflectivity grating, the BBS was turned off, and a pump laser was turned on, so that the laser output could be monitored. Under the condition that the gain compensated the cavity loss, the laser started to oscillate when the grating length reached about 5 mm. We stopped the grating inscription process after the laser output power slightly exceeded the maximal value and finally got the low reflectivity grating with the length of 6 mm. The reflectivity of the low reflectivity grating was estimated to be about 25 dB. Therefore, the total length of the DBR fiber laser was 21 mm, while the lengths of the two FBGs were both 6 mm, separated by a 9-mm-length gain cavity.

3. Experimental setup

Figure 2 shows the schematic diagram of the fiber-optic displacement sensor based on the DBR fiber laser. The fiber laser cavity composed of the low reflectivity grating, Er-doped fiber and the high reflectivity grating is fixed on the PZT. The fiber laser cavity is pretensioned by the PZT to maintain a straight line before the measurement. The whole structure (fiber laser cavity and PZT) is attached to the measured object, and it can withstand compression and tension translated from the measured object, so the length of the fiber laser cavity changes accordingly. Since the central wavelength of the DBR fiber laser is linearly proportional to the longitudinal length of the fiber laser cavity, the central wavelength of the fiber laser will display the pointwise dynamic displacement when the detected point moves along the horizontal direction.

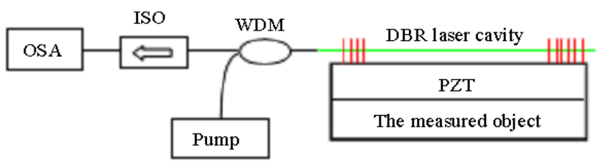

Fig. 2 Schematic diagram of the fiber-optic displacement sensor based on the DBR fiber laser.

The pump light with a wavelength of 980 nm and output power up to 350 mW is incident on the fiber laser cavity through a 980/1550-nm wavelength division multiplexing (WDM). When the gain is compensating the cavity loss, the laser output is from the laser cavity through the WDM and isolator (ISO). When the measured object stretches or contracts with the displacement change, the length of the laser cavity also stretches or contracts accordingly, the central wavelength of the DBR fiber laser is recorded by the OSA, so the displacement is obtained from the central wavelength of the DBR fiber laser.

4. Experimental results

Before the experimental measurement, the cavity of the DBR fiber laser was applied a pretension by the translation stage. The measured object was stretched from 0 to 90 μm in steps of 10μm, and the central wavelength of the DBR fiber laser was recorded by the OSA. Then, the measured object was contracted from 90 μm to 0 in steps of 10μm, and the central wavelength of the fiber laser was recorded by the OSA. Figure 3 shows the central wavelength of the DBR fiber laser with the displacement change of the measured object. The solid rectangles present the loading displacement data, and the solid circles show the unloading displacement data. The solid line is the curve to connect the loading displacement data, and the dashed line is the curve to connect the unloading displacement data. From Fig. 3, the loading curve and the unloading curve are nonlinear, and they don't coincide with each other.

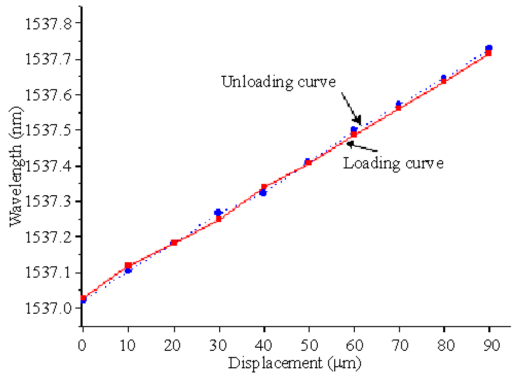

Fig. 3 Results of the fiber-optic displacement sensor measurement.

In order to solve the nonlinearity of the displacement sensor based on the DBR fiber laser, a resistive film bonded to the PZT stack changed the resistance when strain was applied. Up to four strain gages formed a Wheatstone bridge driven by a direct current (DC) voltage. When the bridge resistance changed, electronics converted the resulting voltage change into a signal analogous to the displacement. The sensor real-timely monitored the stretch or contract of the PZT in closed-loop PZT operation. Figure 4 shows the results of the fiber-optic displacement sensor calibration based on the closed-loop PZT.

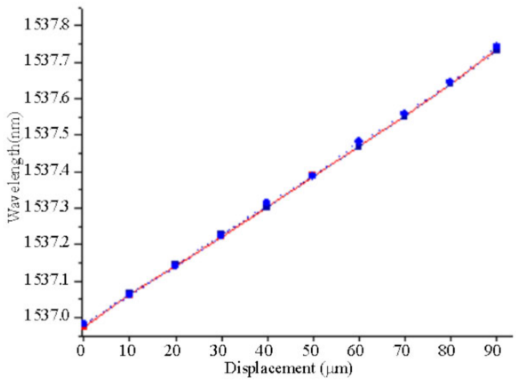

Fig. 4 Results of the fiber-optic displacement sensor calibration based on closed-loop PZT.

Likewise, the closed-loop PZT was stretched from 0 to 90 μm in steps of 10μm, the central wavelength of the DBR fiber laser was recorded by the OSA. Then, the closed-loop PZT was contracted from 90 μm to 0 in steps of 10 μm, and the central wavelength of the fiber laser was recorded by the OSA. From Fig. 4, the solid rectangles present the loading displacement data, and the solid circles show the unloading displacement data. The solid line is the curve to connect the loading displacement data, and the dashed line is the curve to connect the unloading displacement data. From Fig. 4, the loading curve and the unloading curve are linear, and they coincide with each other, because the response of the PZT is linear with the closed-loop operation.

In order to observe the measurement accuracy of the displacement sensor based on the DBR fiber laser, the measuring distance of the displacement sensor was 50 μm and 90 μm, respectively, and the data were measured and recorded 20 times every 10 minutes by the displacement sensor. Figures 5 and

6 are the measurement accuracy of the displacement sensor at 50 μm and 90 μm, respectively.

In Figs. 5 and 6, the solid rectangles represent the measured data by the displacement sensor every 10 minutes. The solid line represents the actual displacement data. In Fig. 5, the measured data are very close to the actual data, and the maximum error is less than 0.28 μm. But in Fig. 6, almost all the measured displacement data are deviated from the actual data, and the maximum error is less than 0.39 μm, because the output wavelength of the DBR fiber laser is not stable with the excessive stretch of the fiber laser cavity.

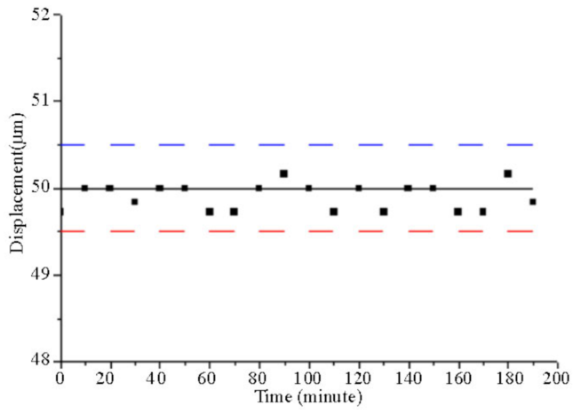

Fig. 5 Measurement accuracy of the displacement sensor at 50 μm.

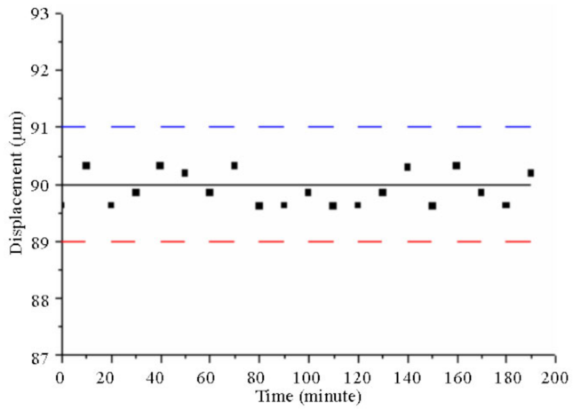

Fig. 6 Measurement accuracy of the displacement sensor at 90 μm.

5. Conclusions

The fiber-optic displacement sensor based on the DBR fiber laser was proposed. The fiber laser cavity was attached to the measured object, which constituted a fiber-optic displacement sensor. In view of the nonlinearity of the displacement sensor, the calibration based on the closed-loop PZT was applied to improve the linearity of the displacement sensor. Experiment results showed that the fiber-optic displacement sensor had a linear response with the nominal working distance of 90 μm.

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