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A fiber laser sensor for liquid level and temperature based on two taper structures and fiber Bragg grating

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ABSTRACT

A fiber laser sensor for simultaneous measurement of liquid level and temperature is proposed and demonstrated experimentally. The sensor is based on two taper structures and a fiber Bragg grating (FBG). The two taper structures form a novel fiber interferometer, which is fabricated by cascading two tapers in a section of single-mode fiber (SMF). The FBG and the interferometer serve as the filters of the laser cavity. Corresponding to the two filters, the laser outputs are stable dual-wavelength outputs, which have different characteristics to the liquid level and the temperature. The wavelength produced by the FBG is not sensitive to the liquid level. The temperature sensitivity of the wavelength produced by the FBG is 0.0123 nm/°C. The wavelength produced by the interferometer is sensitive to the liquid level and the sensitivity is up to 0.2294 nm/mm. The temperature sensitivity of the wavelength produced by the interferometer is 0.0648 nm/°C. According to the different spectral responses of the liquid level and the temperature, simultaneous measurement can be realized. Furthermore, the proposed sensor has the advantages of less detection limit (DL), higher resolution and higher sensitivity compared to other optical fiber sensors.

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1. Introduction

In petroleum, chemical industry and military departments, the measurements of the liquid level are very important. In some special applications such as oil depot and warship, there are some special requirements for the measurement [1–3]. For example, fire protections and anti-electromagnetic interferences are needed. Optical fiber sensors can solve the above problems particularly well. Many optical fiber sensors are reported to implement the measurement of the liquid level, such as long-period fiber grating (LPFG), Fabry–Perot (F–P) combined with fiber Bragg grating (FBG) and so on [4–7]. But sometimes, the temperature also changes when the liquid level changes. These methods can not realize the simultaneous measurement of the liquid level and the temperature.

Recently, fiber laser sensors have attracted more and more attention because of their high sensitivities [8,9]. In this paper, a fiber laser sensor for simultaneous measurement of the liquid level and the temperature is proposed and demonstrated experimentally. The sensor is based on two taper structures and a FBG. The two taper structures form a novel fiber interferometer, which is fabricated by cascading two tapers in a section of single-mode fiber (SMF). The interferometer can realize the coupling and the recoupling between the core mode and the cladding modes. The FBG and the interferometer serve as the filters of the laser cavity. Corresponding to the two filters, the laser outputs are stable dual-wavelength outputs, which have different characteristics to the liquid level and the temperature. The simultaneous measurement of the liquid level and the temperature can be realized by the different sensitivities of two output wavelengths to the liquid level and the temperature. Compared to other optical fiber sensors, the proposed sensor has the advantages of less detection limit (DL), higher resolution and higher sensitivity. It can be used in the measurement of the small liquid level [10] and in the alarm switch of the liquid level.

2. Fabrication and principle of interferometer

The schematic diagram of the proposed interferometer is shown in Fig. 1(a). The interferometer is fabricated by cascading

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two tapers in a section of SMF. Fig. 1(b) shows the microscope image of the taper. A commercial fusion splicer is used to fabricate the taper through manual splicing mode. A section of SMF (8.2 μm/125 μm) is cleaved and put into the fiber fusion splicer. The parameters of the discharge are as follows: the discharge time is 1350 ms, and the discharge intensity is 170 bit. After the discharge, the first taper is realized. The length of the taper is 410 μm and the diameter of the taper area is 60 μm. The method of the second taper is the same as that of the first one. The length of the SMF between the two tapers is L.

The first taper acts as a mode coupler, which makes the input light coupled to the core and cladding of the SMF. The middle SMF acts as sensing section. The second taper also acts as a mode coupler. The lights of the core mode and the cladding modes interfere with each other at the second taper.

The wavelength of the interference peak can be expressed as [11]

$$\lambda_p = \frac{\Delta n_{eff} L}{M} \tag{1}$$

where M is a integer, Δn_{eff} is the difference of the effective refractive index between the core mode and the cladding modes and L is the length of the SMF between the two tapers. The value of L determines the free spectral range (FSR) of the interference peak of the interferometer.

The transmission spectrum of the interferometer is shown in Fig. 2. It can be seen that the FSR of the interference peak is more than 20 nm when L is 2 cm. If L is too long, the FSR of the interference peak will decrease.

The wavelength shift caused by the variation of external parameter (temperature and liquid level) can be described as

$$\Delta\lambda_{co-cl} = \lambda_{co-cl}\left(\alpha + \frac{\xi_{co} n_{co} - \xi_{cl} n_{cl}}{n_{co} - n_{cl}}\right)\Delta T + \lambda_{co-cl}\left(\frac{n_{cl} - n_{cl}^{liquid}}{L(n_{co} - n_{cl})}\right)\Delta l \tag{2}$$

where α is the thermal expansion coefficient, ξ_{co} and ξ_{cl} are the thermo-optical coefficients of the core mode and the cladding mode of SMF respectively. Because the thermo-optical coefficient of the core mode is higher than that of the cladding mode, the wavelength of the interference peak shifts to longer wavelength with the temperature increasing. n_{co} and n_{cl} are the effective refractive index of the core mode and the cladding mode of the SMF respectively. n_{cl}^{liquid} is the effective refractive index of the cladding mode of the SMF in the liquid. It can be seen that the wavelength shifts are also function of the refractive index and the liquid level of the measured liquids. So the sensor can be used in the measurements of the temperature, the refractive index and the liquid level of the measured liquids.

3. Experimental result and discussion

Fig. 3 shows the schematic of the proposed fiber laser sensor. A 7 m erbium-doped fiber (EDF) pumped by a 980 nm laser diode (LD) serves as the gain medium through a 980/1550 nm wavelength division multiplexer (WDM). An optical isolator (ISO) is utilized to ensure a unidirectional propagation of the laser and also to enhance the side-mode suppression ratio (SMSR) by compressing the backward amplified spontaneous emission (ASE). A variable optical attenuator (VOA) is used to control the loss of the cavity. A FBG and a interferometer are used as wavelength filters. The FBG is fed into the cavity through a circulator. The FBG and the

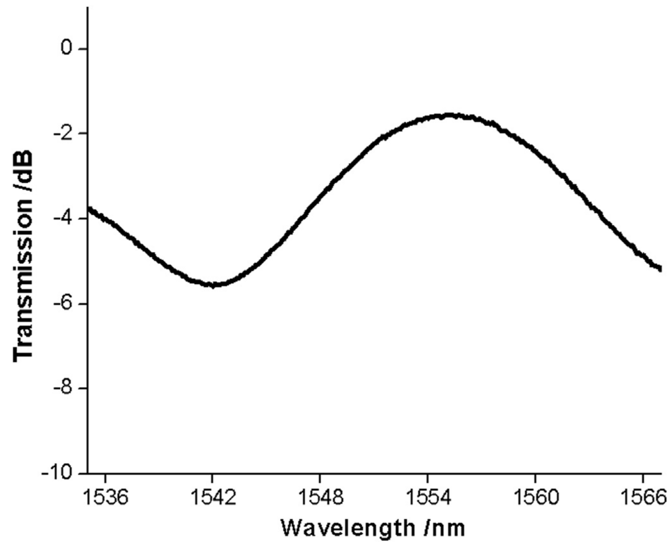

Fig. 2. Transmission spectrum of the interferometer.

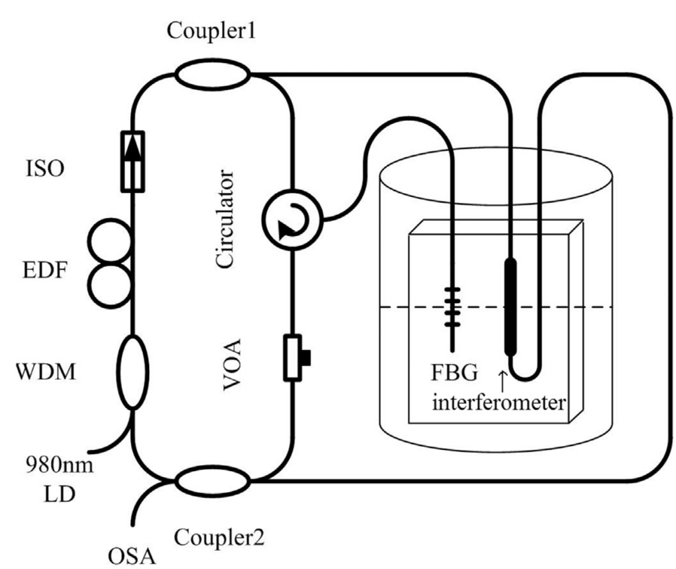

Fig. 3. Schematic diagram of the experimental setup.

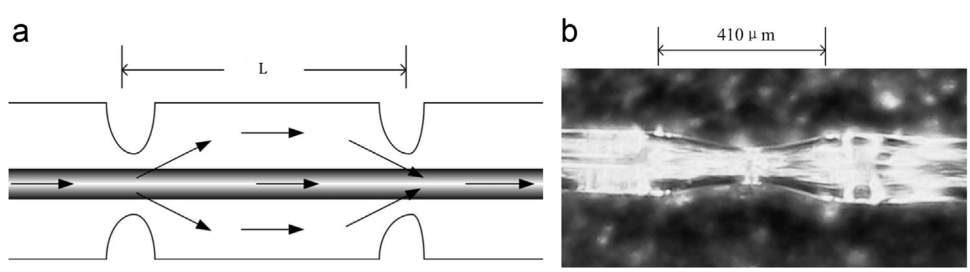

Fig. 1. (a) Schematic diagram of the interferometer. (b) Microscope image of the taper.

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