Intensity-modulated refractometer with long period fiber grating cascaded by chirped fiber grating

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ABSTRACT

An intensity-modulated refractometer is proposed and experimentally demonstrated by using a long period fiber grating (LPG) cascaded with a chirped-fiber Bragg grating (CFBG). The reflection wavelength band of the CFBG was properly selected to contain the most sensitive spectral part of the LPG. As a result, intensity of the reflected signal was modulated linearly by refractive index (RI) of surrounding liquid outside the LPG. RI measurement in a range from 1.33 to ~1.45 was realized with enhanced sensitivity up to 48.93 μW/R.I.U.

Keywords: Refractometers; long period fiber gratings; chirped-fiber Bragg gratings; optical fiber sensors.

1. INTRODUCTION

Refractometers based on optical fibers have been widely investigated and applied in areas such as biomedical monitoring, environmental measurements and so on due to their many advantages including compactness, electromagnetic interference immunity, and electrically passive operation [1-3]. Optical fiber gratings including Bragg gratings [2, 4-6], long period gratings (LPGs) [7] and tilted-fiber Bragg gratings (TFBGs) [8, 9] are good candidates with their unique self-referencing capability. Among them, LPGs have attracted more research attentions because they show relatively high sensitivity to surrounding refractive index (RI). However, two limitations of LPG-based sensors that have not been adequately addressed are the transmission operation mode and the wavelength demodulation method, which cause inconvenience in many practical sensing applications. Some reflective LPGs were proposed by using cladding-mode-selective fiber end-face mirror [11], Sagnac fiber loop mirror [12] or Michelson interferometer [10], but most of reflective LPGs are still demodulated by wavelength measurement. Recently, an novel design based on a TFBG cascaded with a chirped-fiber Bragg grating (CFBG) was developed by us and used for RI measurements [14], magnetic field [15] and relative humidity [16]. It shows good potentials with its low cost intensity-demodulation method and convenient reflection operated mode.

In this paper, an intensity-modulated refractometer is proposed and experimentally demonstrated by using a LPG cascaded with a CFBG. The reflection wavelength band of the CFBG was properly selected to contain the most sensitive spectral part of the LPG. As a result, intensity of the reflected signal was modulated linearly by RI of surrounding liquid outside the LPG. RI measurement in a range from 1.33 to ~1.45 was realized with enhanced sensitivity.

2. SENSOR FABRICATION AND PRINCIPLE

The LPG was fabricated by using a high-frequency pulsed CO_2-laser (CO_2-H10, Han's Laser) with a maximum average output power of 2W. The period of the LPG is about 472.3 μm and the grating length is 18.9 mm (40 grating periods). The resonance wavelength locates at 1557.7 nm with loss of ~ 30 dB in transmission. The CFBG used was manufactured in a hydrogen-loaded single-mode fiber by using the phase mask method with a frequency-doubled Argon laser emitting at 244 nm. The CFBG is 45-mm long, with reflectivity of ~14 dB in a broad and reflection band of ~40 nm (1525-1565nm), which cover the resonance wavelength region of the LPG. Figure 1(a), (b) and (c) show respectively the

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24th International Conference on Optical Fibre Sensors, edited by Hypolito José Kalinowski, José Luís Fabris, Wojtek J. Bock, Proc. of SPIE Vol. 9634, 96346F · © 2015 SPIE
CCC code: 0277-786X/15/$18 · doi: 10.1117/12.2194765

measured transmission spectrum of the LPG, reflection spectrum of the CFBG and reflection spectrum of the LPG cascaded with the CFBG. It can be seen in Figure 1(c) that the dip wavelength of the LPG was the same as shown in Figure 1(a) but the depth at the dip wavelength was increased to ~45 dB because the light propagates through the LPG twice.

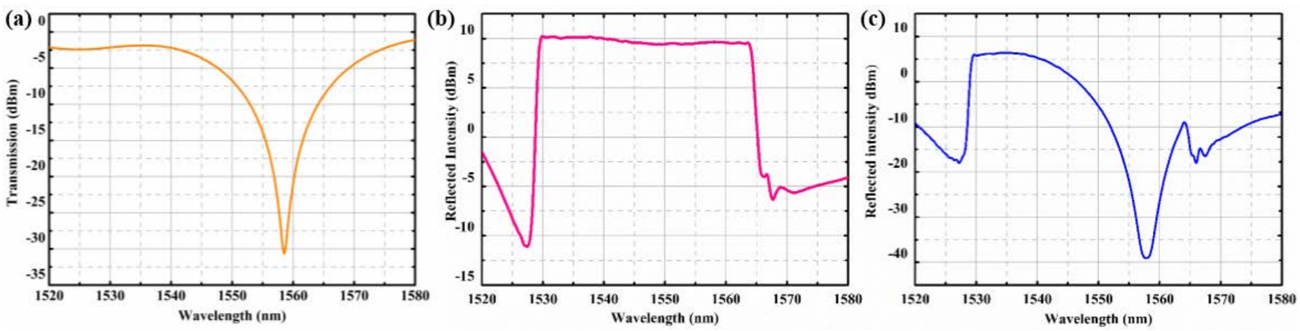

Figure 1 (a) Transmission spectrum of the LPG; (b) Reflection spectrum of the CFBG. (c) Reflection spectrum of the LPG casecaded with the CFBG.

When the optical signal passes through the LPG, modes coupling between core mode and cladding mode happens according to the phase matching condition,

$$\lambda_{(x)} = (n_{core} - n_{clad(x)})\Lambda \tag{1}$$

where $\lambda_{(x)}$ is the resonance wavelength of LPG at which the coupling occurs, n_{core}, $n_{clad(x)}$ is the effective refractive indices of the core mode and the cladding mode respectively. Λ is the period of the LPG. While the surrounding RI changed, it increases the value of $n_{clad(x)}$ and the LPG resonance wavelength will shift to the short direction.

After reflected by the CFBG, the modulated optical signal will pass through the LPG again that enhances the mode coupling efficiency and hence modulation effect of surrounding RI to the reflected optical signal. That makes the intensity-demodulation possible. In addition, the operation mode of the proposed sensor is changed from transmission to reflection, providing obvious convenience in practical measurements.

3. EXPERIMENTAL RESULTS AND DISSCUSSIONS

Figure 2 shows surrounding RI measurement setup with the proposed refractometer. A broadband sources (BBS) whose transmission spectrum is shown in Figure 3, with central wavelength of 1550 nm, was launched into the proposed sensor by using an optical fiber circulator. The reflected optical signal was measured by using an optical spectrum analyzer (OSA, AQ6370) or an optical power meter (OPM). The sensor was kept from any strain or bending. The LPG was covered by glycerin-water solution with various refractive indices in different doping concentrations.

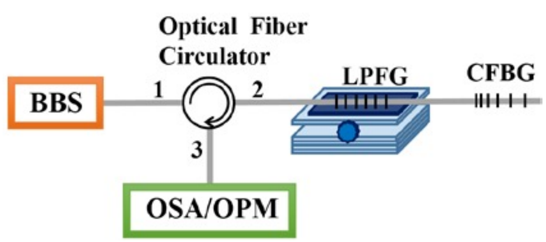

Figure 2 Experimental setup for RI measurement.

When the variation of surrounding RI has an influence on the effective RI of the cladding mode, the resonance of the LPG shifts toward shorter wavelength. The evolution of the normalized reflection spectra of the LPG cascaded by the reflection-band-matched CFBG is shown in Figure 3. It can be found that surrounding RI modulated resonance wavelength region of the LPG was selected properly in the reflection spectra. The reflection region of the CFBG is relatively stable when surrounding RI is changed. The coefficient of the spectra between the LPG and the CFBG make the wavelength shift of the LPG convert to the reflected power variation of the proposed sensor, which make the LPG-based refractometer intensity-demodulation realized. When the surrounding RI changed at low value, the resonance wavelength of the LPG shifts slightly. And then the resonance wavelength shift increases with surrounding RI. The nonlinear response of the resonance wavelength of the LPG brings slightly effect on linear variation of the reflected power. That is caused by the longer wavelength region of the CFBG is close to the 3-dB band of the LPG at the relatively low RI and gradually away from loss region of the LPG when the surrounding RI increases. With the help of the reflection selection of the CFBG to the LPG, the loss of the reflected power with RI is approximately linear as shown in Figure 4.The achieved linear sensitivity to RI is 48.93 μW/R.I.U with the wide range from 1.33 to ~1.45. The linearity is good with the R^2 value of 0.9891.

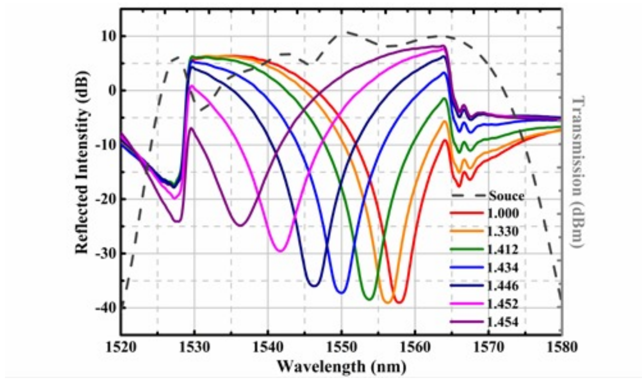

Figure 3 Transmission spectrum of BBS and reflection spectral evolution of the refractometer under various refractive indices.

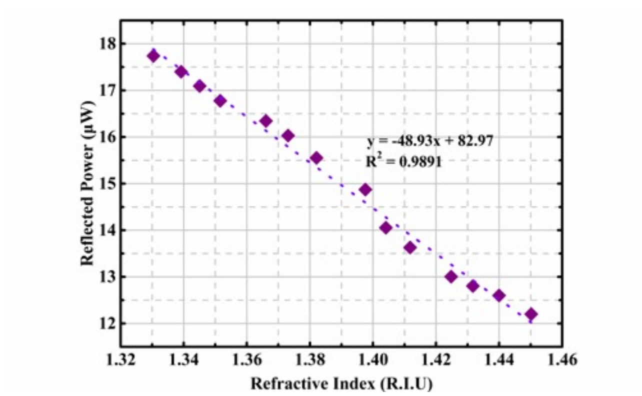

Figure 4 Reflected optical power verse surrounding RI.

Besides the intensity-demodulated measurement method, the proposed sensor has several additional advantages. By cascading the CFBG with the LPG, the optical signal is modulated twice by the LPG thus the sensitivity for RI measurement is enhanced. Moreover the proposed sensor works in the reflection mode, which is more convenient in practical applications.

There are also some limitations like the relatively low respond, but the performance can be improved by using an optimized CFBG with more suitable spectral region and better reflectivity. The respond also depends on the cladding mode participate of the LPG. These factors can be considered by the design of the LPG and the CFBG: its period, length and so on.

4. CONCLUSION

An intensity-modulated refractometer has been demonstrated by using a LPG cascaded with a CFBG. The reflection wavelength band of the CFBG was properly selected to contain the most sensitive spectral part of the LPG. As a result, intensity of the reflected signal was modulated linearly by RI of surrounding liquid outside the LPG. RI measurement in a range from 1.33 to ~1.45 was realized with enhanced sensitivity up to 48.93 μW/R.I.U. The proposed refractometer has many advantages such as compact, easy fabrication and convenience in practical applications.

ACKNOWLEDGMENTS

This work was supported partially by National Natural Science Foundation of China under Grant No. 61475147 and National Natural Science Foundation of Zhejiang Province, China under Grant No. Z13F050003. This work was also supported by the ENERGY MARKET AUTHORITY (LA/Contract No: NRF2013EWT-EIRP001-006).

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