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A study on a long period fiber grating pair's spectral characteristics

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Abstract

This paper demonstrates the spectrums of a long period fiber grating pair (LPGP) by changing the following physical parameters: the separation of the LPG， the length of single LPG and the number of single LPG .The study of the response of the LPGP to different parameters enables a rational design of the sensor element. These results produce an important foundation of our further study of LPGP spectral characteristics. On the basis of the above conclusion, a LPGP is produced by the amplitude mask method, in which the germanium-doped fiber is exposed by the UV. The LPGP's resonance wavelengths are shifted as the refractive index of medium surrounding the cladding of the long-period grating. The sugar solution was experimentally measured, and results show that, this fiber-based device can rely on LPGP's the wavelength drift to differentiate solution's concentration based on their refractive index.

*Keywords:*Long period fiber grating pair; Transmission; Fibre optics; Concentrations in solutions ; Refractive index

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1. Introduction

Long-period gratings emerged a few years ago as a new optical component, interest in fibre LPGs as sensing elements is increasing because of their sensitivity to the environmental changes.Recently, resulting from the Mach-Zehnder interferometer effect, the use of LPG pairs has shown an enhanced performance over a single LPG in terms of the sensor resolution due to the presence of sharp interference fringes. LPGP based sensors measure different physical parameters, namely bending[1] , refractive index [2,3] , strain[4] and temperature[5,6].

Various physical structure parameters of LPGP have determined their transmission spectrum. According to the need of the project and actual make, further investigations on LPGP's spectrum characteristic result from various parameters is very necessary.The LPGP's performance can be enhanced by proper selection of the grating parameters. In this paper,three parameters: the separation of the LPGs, the length of grating, the number of grating which will change the transmission spectrum more or less, are discussed. At last, we demonstrate a LPGP to be used to measure the refractive index by using sugar solution.

2. Theory

Inscribing two or more matched LPGs along an optical fibre, where they are separated by a specified distance, creates a long period grating pair (or a cascaded long period gratings). The principle of operation of long period grating pair is depicted in Fig.1.d is the length of a single LPG is 10mm, while L is the separation between LPGs.

The power is divided in two different propagation regimes after the first grating,i.e. the core and cladding propagation ones. The first LPG couples half of light into a cladding mode while the other half of light propagates in the core mode. The first grating induces the coupling of half the power propagating in the core-mode to the cladding modes at each resonance. The coupled core and cladding modes from the first LPG propagate within the same fiber and combine again at the second matched LPG to form the interference fringes. The core and cladding paths constitute the arms of the Mach–Zehnder interferometer.

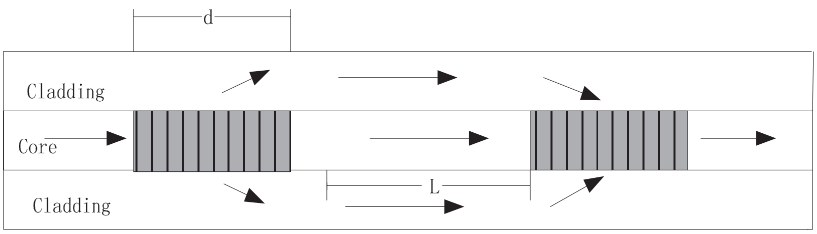


Fig. 1. Schematic of the LPGP

The resonance light propagating in the core, giving rise to the interference pattern.. a set of fringes are observed within the attenuation bands, as seen in figure 2. N=1 is a single LPG's transmission, N=2 is the LPGP's transmission. The transmission of LPGP is composed of periodic SIN function which modulated by several curves of a single LPG transmission spectrum. In Fig 2, S stands for interval of interference fringes while B is the bandwidth of interference fringes. Different parameters, such as the grating length, grating number, and the separation of the LPGs may result in the change of the LPGP's spectral characteristic.

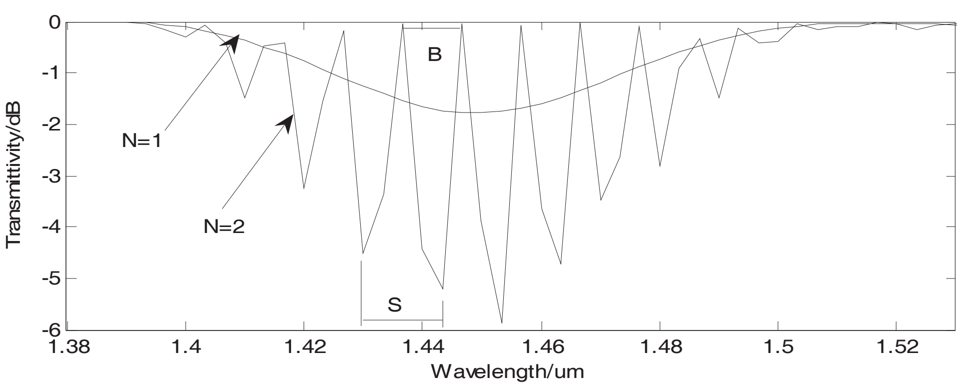


Fig.2. a single LPG and LPGP's transmission spectrum

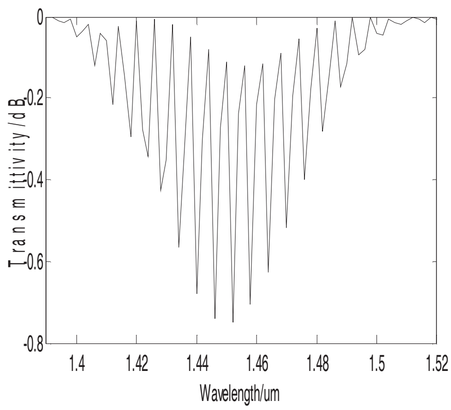
3. 3 The Spectrum characteristic of LPGP of different parameter

In the following research, the main parameters used are as follows: the grating period is 450 μ m, the refractive index modulation is 0.0001, d is 10mm, L is 30mm.

3.1 The separation of the LPGs

For L=10 cm as shown in Fig.3, the wavelength spacing between neighbor transmission peaks is 0.007 nm. As the distance between LPGs increases we obtain a transmission spectrum with narrower transmission peaks closer together.

For L=20 cm as shown in Fig.4, there are 36 transmission peaks, with more than 3 dB extinction spaced by 0.0035 nm. The line width of the transmission peaks is determined by the separation of the LPGs .so we can control the transmission linewidth for specific applications by selecting a suitable separation of the LPGs.



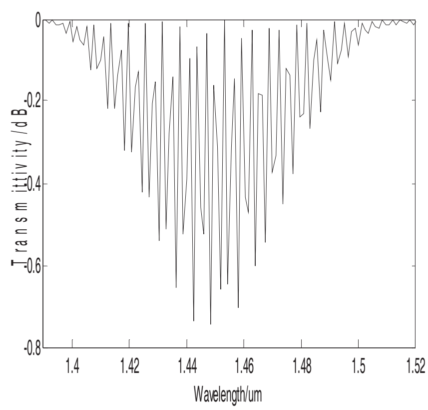
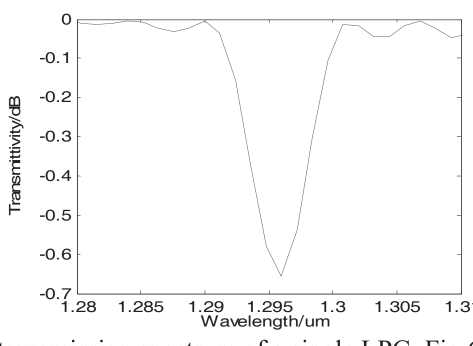


Fig.3 LPGP's transmission spectrum which L is 10cm Fig.4 LPGP's transmission spectrum which L is 20cm

The separation of the LPGs constituting the pair has a significant impact on the LPG pair performance .As the separation increases, a higher number of sharper interference fringes are obtained, and thus the sensor resolution is enhanced. However, considering the practical application, lager LPG separations allow the fiber to be mechanically weaker. A larger separation between the single LPG make the total physical length of a LPG pair to be larger. It is inconvenient in some test. The stripped fibre between the LPG gratings is the LPGP's sensing region, larger of which is , less precise in its positioning for the measurement carried out.

The LPGP has narrower rejection bandwidth than the LPG as shown in Fig.5 and Fig.6, which may increase the resolution of a measurement. The narrower bandwidth of the fringe facilitates greater resolution in the measurement of the wavelength than is possible with conventional LPGs. Proper separations between LPG are chosen to obtain fine interference fringes in the transmission spectrum, which can be utilized to significantly enhance the resolution.

With the separations between LPG increased, bandwidth reduce, loss peak become narrower and deeper, the wavelength of the resonance peak does not change. For multi-wavelength filter, changing the separations between LPG is the effective way to alternate the grating interval.



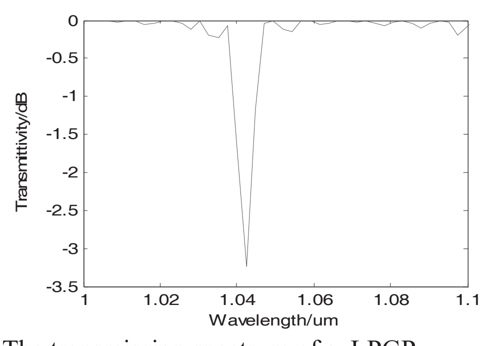
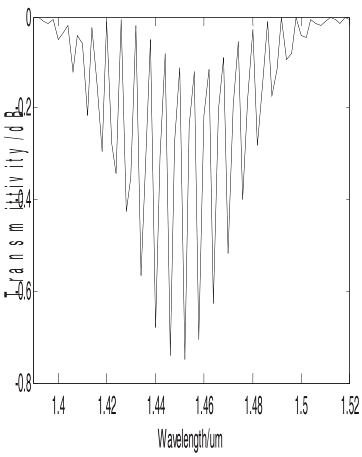


Fig.5 The transmission spectrum of a single LPG Fig.6 The transmission spectrum of a LPGP

which L is 30cm

3.2 The length of grating



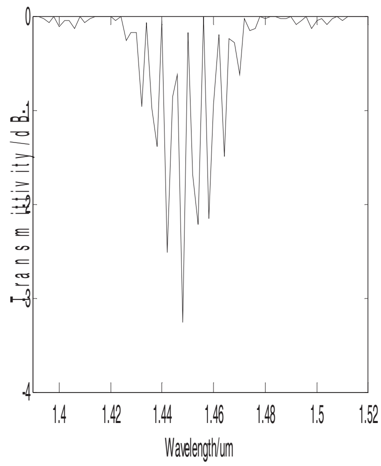
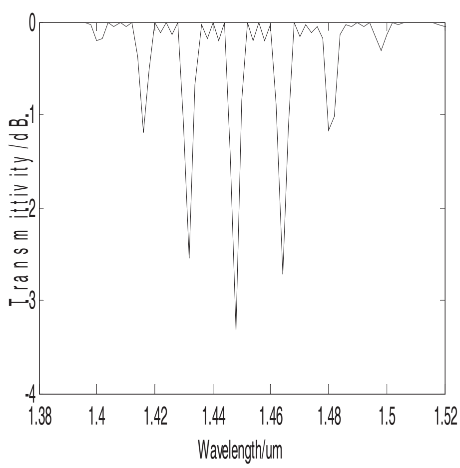


Fig.7 The transmission spectrum of LPGP which d is 10mm Fig.8 The transmission spectrum of a LPGP which d is 20mm

It can be seen by comparing Figure 7 with Figure 8, the number of interference fringes within the envelope of LPG's loss peak in Figure 7 is the twice or more than that in Figure 8. Therefore, the interference fringes' number of a LPG pair is inversely proportional to the length of the grating. While the grating length is inversely proportional to the bandwidth of grating, so the shorter the grating is, the wider the bandwidth is. For the LPG pair, the transmission spectra has more number of interference fringes with the shorter length grating.

3.3 The number of grating



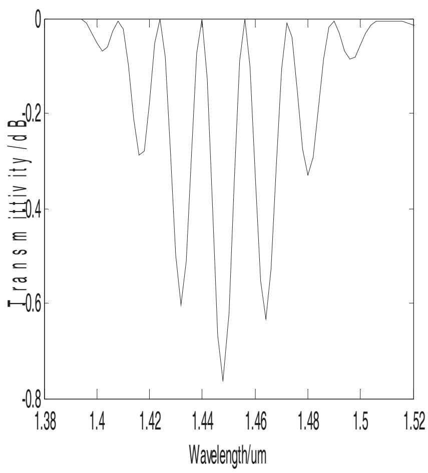


Fig.9 The transmission spectrum of a LPGP which the cascaded number of grating is 2

Fig.10 The transmission spectrum of a LPGP which the cascaded number of grating is 4

As Figure 9 and Figure 10 can be seen, with the number of N cascaded LPG increased, the number of interference peaks remain unchanged, but each bandwidth of the interference peaks becomes narrower ,thus the interference peaks get sharper, the distance between adjacent transmission peaks is larger. The amplitude of the interference peak increases with the raise of N.

If LPGP is designed to multi-wavelength isolator or comb filter, with the increase of the number of gratings, the isolation of adjacent channel also enhances, the device's performance will be more advantageous.The price of LPG is generally expensive and the production of the same loss peak wavelength and depth is difficult, while such a grating itself is very sensitive to outside interference. With the number of LPG increasing, the device stability will be more difficult to control, so the actual system is generally not used more LPG to cascade.

Generally, LPGP sensors offer flexibility to the designer, to arrive at either high sensitivity or high resolution performance by adjusting various fabrication parameters, such as the LPGs' physical lengths, the separation between the single LPGs, the degree of optical coupling and/or the host fibre material/structure.

4. Experimental set-up and results

On the basis of the above conclusion, a LPGP is produced by the amplitude mask method, in which the germanium-doped fiber is exposed by the UV.The parameters designed are as below:the Central wavelength is 1530nm, d is 3cm, L is 10cm.

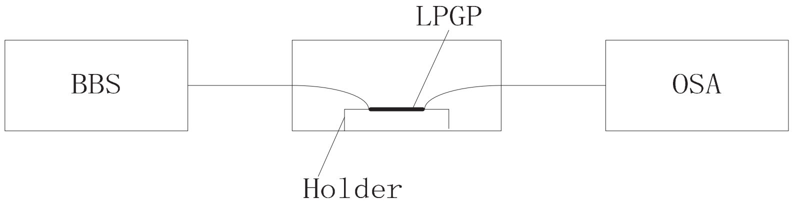


Fig.11 The experimental apparatus of LPGP

The sugar solution were measured at room temperature by using such a LPGP. The experimental apparatus is shown in Fig.11. A Broadband light source (Agilent 83437A)was used as input, The wavelength shift was observed continuously using an Optical Spectrum Analyzer (Agilent AQ6317C).During the measurements, the temperature was maintains at 25 degrees in order to avoid wavelength shifts due to temperature variations.The fiber was maintained straight and at each end of the LPGP a given weight was attached. All readings were taken several minutes after the LPGP was immersed in the solution,for it will take some time for sugar to dissolve,different amount of sugar were put in 150 ml water each time.The amount of sugar was increased from 20g to 160g with 20g increment. The Sugal solutions' refractive index can be read by Abbe refractometer.

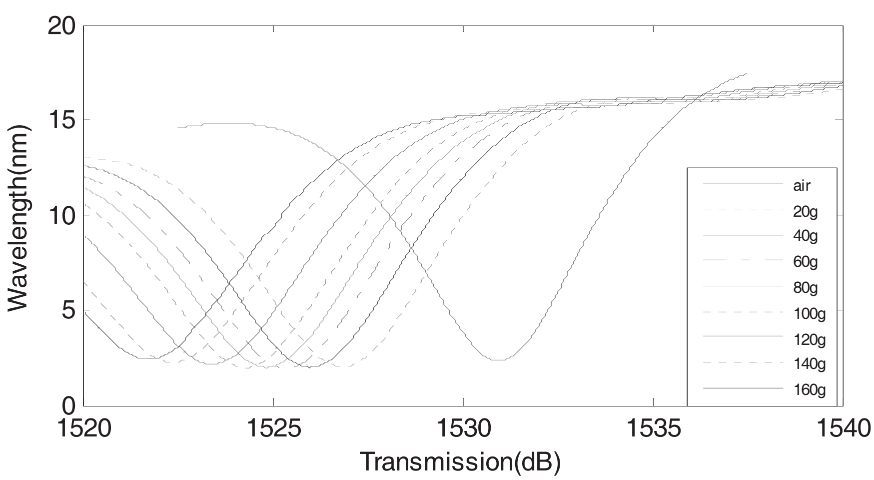


Fig.12 Transmission spectra of sugar solutions which have different concentration

It can be seen in Fig.12, when the sugal solutions' refractive index or concentration were changed,the position of the LPG's resonant peak was also altered. With increasing bending, the resonant peak shifts to shorter wavelength.In Fig.12,we also can see the peak attenuation of the transmission spectrum when the LPG was immersed in solutions with respect to the spectrum in air. When the LPGP was put in the sugal solution the the resonant peak shifts to shorter wavelength and then the central wavelength of was increaseed, but finally stabilized on a corresponding shorter wavelength.Experimental data points could be fitted by using polynomial regression. The relationship between wavelength of attenuation band and the Sugal solutions' concentration was obtained by a linear fitting equation as shown in Fig.13.

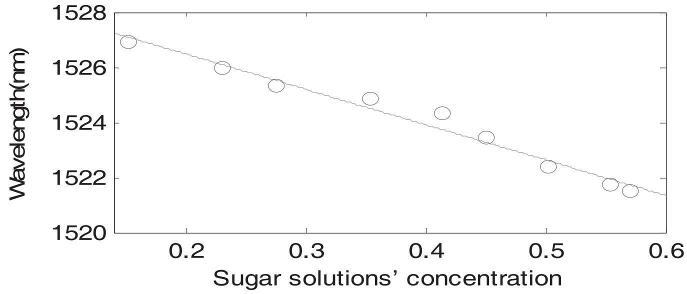


Fig.13 Wavelength response of the LPGP when the Sugar solutions' concentration is changed.

Within the range of sugar's solubility, the solution concentration and its refractive index a has a linear relations approximately as shown in Fig.14. In unknown environment, we can observe the shift of wavelength to obtain the solutions' refractive index , and then get the solutions' concentration. The abbe refractometer has about 2*10-3 resolution, and it can only measure refractive index off-line. While the LPGP's resolution can reach 10-5 and can be test on-line.

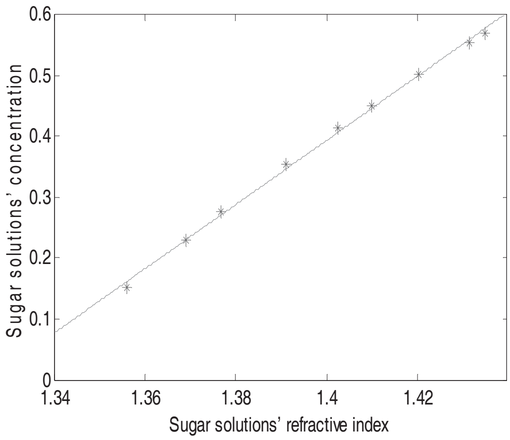


Fig.14 The relationship between the sugar solutions' concentration refractive index

5 Conclusion

The impact of the change of LPGP's parameters on spectrum are discussed in this paper and some meaningful results have got: The separation between LPG increases, a higher number of sharper interference fringes are obtained, and thus the sensor resolution is enhanced;with the number of N cascaded LPG increased, the number of interference peaks remain unchanged, the interference peaks get sharper, and the amplitude of the interference peak increases with the raise of N;while the interference fringes' number of a LPG pair is inversely proportional to the length of the grating. the grating length is inversely proportional to the bandwidth of grating,

The results of LPG's spectral characteristics, which can provide the theoretical basis for LPG's design, parameter optimization are obtained. In this paper, the LPGP fiber sensor were used for measuring the concentration of sugar.The achieved resolutions were better than those offered by conventional Abbe refractometers, The obtained results have demonstrated the LPG potential to provide a relative measurement of concentration in solution.

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