SAMPLED LONG-PERIOD FIBER GRATING FILTERS WITH NARROW STOP BANDS

Xinyong Dong,[1] Ningning Pan,[2] Ping Shum,[2] and Chi Chiu Chan[3]
[1] Institute of Optoelectronic Technology, China Jiliang University, Hangzhou, China; Corresponding author: dong_x_y@hotmail.com, xydong@cjlu.edu.cn
[2] Network Technology Research Centre, Nanyang Technological University, Singapore
[3] School of Chemical and Biomedical Engineering, Nanyang Technological University, Singapore

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ABSTRACT: *Band-stop fiber-optic filters based on sampled long-period gratings (S-LPGs) have been fabricated and studied experimentally. Comparison between transmission spectra of the proposed S-LPGs and normal LPGs have been carried out. It has been found that S-LPGs possess much narrower stop bands than the corresponding normal LPGs, though their transmission spectra are similar. Experimental results also show that S-LPGs have the same strain and temperature sensitivities as normal LPGs written in the same fiber.* Microwave Opt Technol Lett 51: 2401–2403, 2009; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.24627

Key words: *long-period fiber gratings; optical fiber filters; tunable filters*

1. INTRODUCTION

Optical fiber gratings are well-known as the devices that couple the fundamental core mode of a single-mode optical fiber to the counter propagating core mode or several co-counter propagating cladding modes, depending on the periodicity of the grating fabricated along the fiber core. Fiber grating-based filters have been studied extensively as an excellent type of filter elements which are inherently compatible to the present optical fiber networks with very low insertion losses. Their versatility and unique filtering capabilities, arising from the greatly variable structural parameters of fiber gratings, have produced a large number of applications in the optical fiber communication and sensor areas. For example, sampled fiber Bragg gratings, which are realized by a simple technique of sampling of the grating structure, allow reflection of multiple wavelengths with very narrow linewidth. Hence they can be applied as a wavelength selective component in multiwavelength fiber lasers [1].

Long-period fiber gratings (LPGs) are an important type of fiber gratings which can be fabricated in a single-mode optical fiber with a much longer period than that of fiber Bragg gratings, normally around several hundred micrometers. Mode coupling in LPGs happens between the fundamental core mode and several counter-propagating cladding modes, resulting in a series of stop-bands in the transmission spectrum. LPG-based filters, including the LPG-pair based in-fiber Mach-Zehnder interferometers have been widely studied and used in various optical fiber systems [2–7]. However, few attentions have been paid to LPG filters with sampled grating structures. In this article, a band-stop filter based on a sampled-LPG (S-LPG) was fabricated and studied. Its transmission spectra for cases of different number of samples were compared with those of normal LPGs with the same periods and same real grating lengths. Their responses to strain and temperature were also measured.

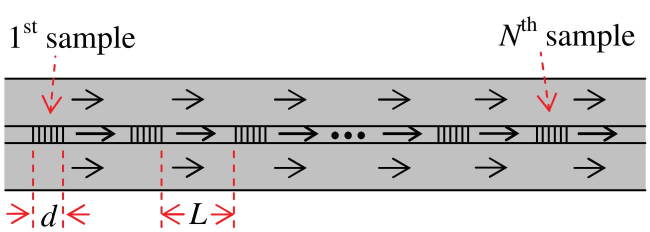

Figure 1 Scheme diagram of a sampled long-period grating with a sample number of *N*. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

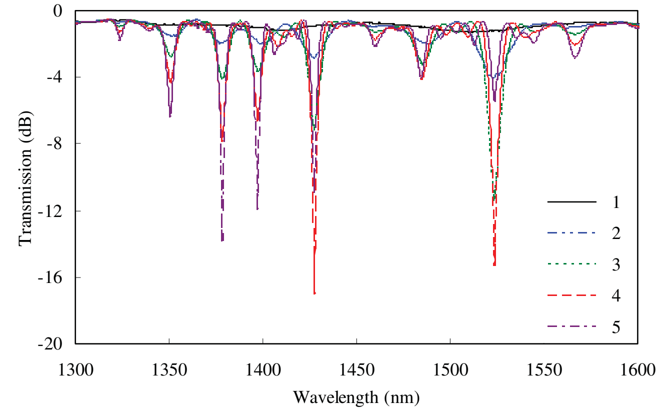

Figure 2 Measured transmission spectra of the S-LPG with different sample numbers of 1 to 5. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

2. FABRICATION AND SPECTRAL MEASUREMENTS

Figure 1 shows the configuration of an S-LPG with a grating sample number of *N*. It was fabricated by using a beam scanning method along a photosensitive single-mode optical fiber with a continuous Argon laser beam at wavelength of 244 nm. An amplitude mask with a grating period of 475 μm was also used. The grating samples were fabricated one by one and the fiber space in-between were introduced by shutting off the Argon laser and moving the laser beam by a translation stage to the beginning position of the next grating sample. The UV laser power and scanning speed were 100 mW and 0.1 mm/s, respectively. The length of the amplitude mask was quite large so that it was kept fixed during the whole process of grating fabrication. That reduced the fabrication difficulty of relatively long sampled gratings and avoided any arbitrary phase shift introduced possibly by mask alignment. Because the period of an LPG, normally several hundred of micrometers, is much larger than that of a fiber Bragg grating, the grating sample could not be so short to include several periods only in each sample. At the same time, the fiber space in between should be short so that the total length of the grating filter is reasonable and acceptable for most cases. In the following experiment, an S-LPG with grating sample length of 5 mm and fiber space length of 5 mm too was fabricated and studied. For the purpose of comparison, a normal LPG without sampling was also fabricated under the same conditions. Spectrum measurement was performed by using a broadband light source and an optical spectrum analyzer (Ando AQ6317).

Figure 2 shows the measured transmission spectra of the fabricated S-LPG when different number of grating samples from 1 to 5 were fabricated. It can be seen that five main stop bands at 1350.6, 1378.4, 1397, 1427.6, and 1523.8 nm were generated.

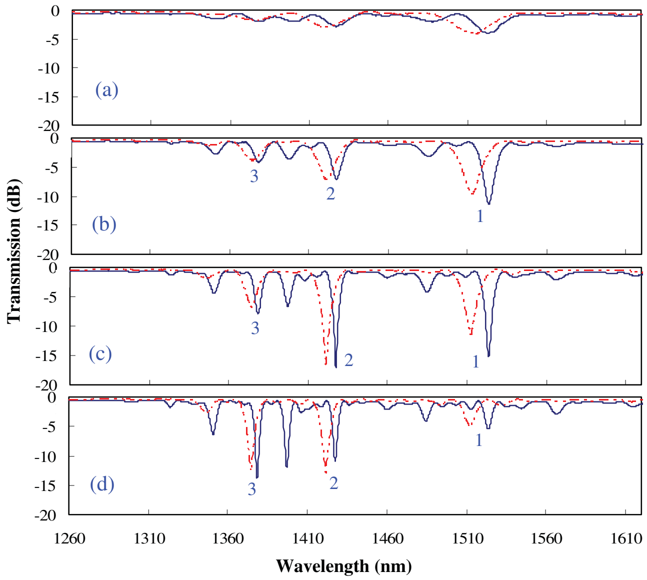

Figure 3 Spectrum comparison between S-LPG (solid curves) and normal LPG (dashed curves) when their real grating lengths are (a) 10, (b) 15, (c) 20, and (d) 25 mm. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

With increasing the sample number the stop bands grew first and then decayed after approaching a maximum depth due to the over coupling between the fundamental core mode and the corresponding cladding modes. Note that stop bands at longer wavelengths approached maximum depths sooner than those at shorter wavelengths because the mode coupling efficiency is higher for a higher order cladding mode than a lower order one. At the same time, the bandwidths of those generated stop bands became narrower and narrow. For example, bandwidth of the stop band at 1523.8 nm was 11.7, 8.6, and 4.0 nm when the sample number was 3, 4, and 5, respectively. It was reduced rapidly with increase of the number of grating samples.

Since the stop bands of a normal LPG without sampling will also become narrow with increase of the grating length, we made a normal LPG with the same grating period under the same fabrication conditions for comparison. Figure 3 shows the transmission spectra of the S-LPG with different sample number of 2 to 5 and the corresponding normal LPG with equal actual grating lengths. It was found that their transmission spectra are quite similar. Stop bands were located at similar wavelengths and the coupling strength for each stop band is approximately the same. An additional stop band appeared at 1397 nm for the S-LPG may be related to the interference between the core mode and a cladding mode, and the slight red shift of other stop bands of the S-LPG were caused by phase shift introduced by the fiber space between adjacent grating samples. It is worth noting that each stop band of the S-LPG is narrower than the corresponding one of the normal LPG. Table 1 shows the detailed comparison in bandwidth of stop bands between them. It can be seen that ~40% narrower in bandwidth was achieved in all the listed cases in Table 1.

3. SIMULATION AND ANALYSIS

Numerical studies of S-LPGs have been performed based on the coupled-mode theory with transfer matrix method introduced in [8]. Generally, the input beam of the S-LPG incidents from the core of the fiber, thus, the initial condition amplitude can be set as

$$\begin{bmatrix} a_{co}(0) \\ a_{cl}^{v}(0) \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \tag{1}$$

After passing through a grating sample of length d, as depicted in Figure 1, if the beam propagates further to a grating-free region of length L, the modal amplitudes become

$$\begin{bmatrix} a_{co}(d+L) \\ a_{cl}^{v}(d+L) \end{bmatrix} = \begin{bmatrix} \exp[i\beta_{co}L] & 0 \\ 0 & \exp[i\beta_{cl}^{v}L] \end{bmatrix} \begin{bmatrix} a_{co}(d) \\ a_{cl}^{v}(d) \end{bmatrix} \tag{2}$$

where a_{co} and a_{cl}^{v} are the amplitudes, and β_{co} and β_{cl}^{v} are the propagation constants of the core mode and the vth-order cladding mode, respectively. After passing N grating samples, we get the modal amplitude $a_{co}(N(d+L))$. The modal intensity measured as the spectrum of the device is given by the square of the norm of the corresponding modal amplitude,

$$\begin{bmatrix} T_{N} \\ R_{N} \end{bmatrix} = \begin{bmatrix} \|a_{co}(N(d+L))\|^{2} \\ \|a_{cl}^{v}(N(d+L))\|^{2} \end{bmatrix} \tag{3}$$

where T_N and $R_N$are defined as the modal intensities of the core mode and the cladding mode, respectively, after passing the cascaded N grating samples. However, after passing the device, the coupled cladding mode decays rapidly due to the absorption and scattering by the coating over the cladding. Therefore, with a conventional optical spectrum analyzer, only the core-mode density can be measured. Base on the above analysis, we calculated the transmission spectra of the designed S-LPG with different numbers of samples. Figure 4 shows the simulation results of the S-LPG with 4 and 5 grating samples, compared with the measured data. Good agreements have been achieved between them.

4. STRAIN AND TEMPERATURE PROPERTIES

The strain and temperature properties of this S-LPG have been measured and compared with those of the normal LPG. To measure the temperature sensitivity, the above-fabricated S-LPG with five grating samples and a normal LPG with a length of 25 mm were put into an oven and heated up from 30°C to ~150°C. To measure the strain sensitivity, one end of the gratings was fixed and the other end was stretched. The transmission minimums of their first stop bands were tracked and the measured data are shown in Figure 5. It can be seen that, in both cases the wavelengths of both gratings shift toward longer wavelength direction in a linear manner. Their sensitivities to temperature and strain are the same, 186 pm/°C and 0.1 pm/$\mu\varepsilon$, respectively. Small discrepancies may be caused by errors of measurement and data reading.

Compared with normal fiber Bragg grating, these photosensitive fiber based LPG filters show ~15 times higher sensitivity to temperature and one order lower sensitivity to strain. They are

TABLE 1 Bandwidth Comparison Between the S-LPG and the Normal LPG

Grating Length (mm)	Stop Band Number	Bandwidth (nm)		Comparison	
		LPG	S-LPG	In (nm)	In (%)
15	1	18.6	11.7	6.9	37.1
	2	13.9	8.0	5.9	42.4
20	1	14.1	8.6	5.6	39.7
	2	12.4	6.9	5.5	44.4
	3	9.4	5.4	4.0	42.6
25	1	6.7	4.0	2.7	40.3
	2	9.1	4.8	4.3	47.3
	3	9.0	5.1	3.9	43.3

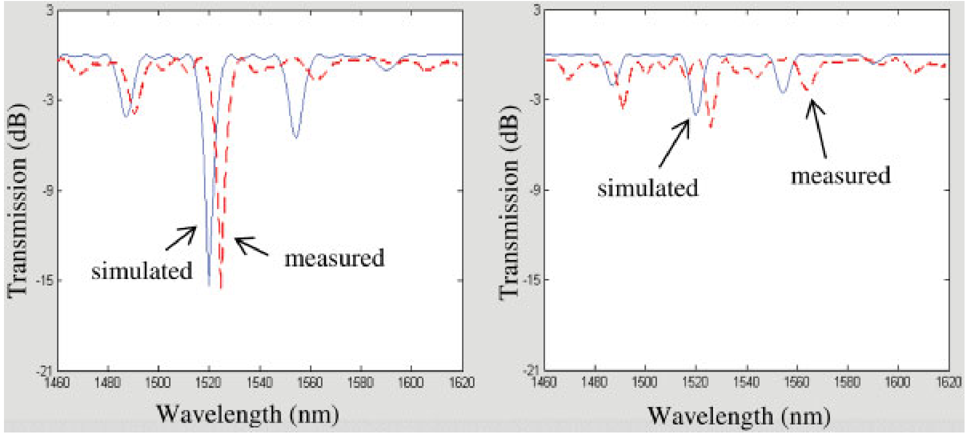

Figure 4 Comparison between simulation and experimental results of the S-LPG when the number of grating samples is (a) 4 and (b) 5. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

preferable to be used as high-sensitivity temperature sensors, but for normal LPG based sensors, one of the most serious barriers for their practical applications is the broad bandwidth which causes poor reading accuracy of the LPG's transmission minimum or maximum. Now with the proposed S-LPGs, the bandwidths of their stop bands are reduced so the reading errors can be suppressed significantly. Further studies focused on achieving narrower stop bands of this S-LPG are in process. High-performance temperature sensors based on this novel LPG technology are expectable.

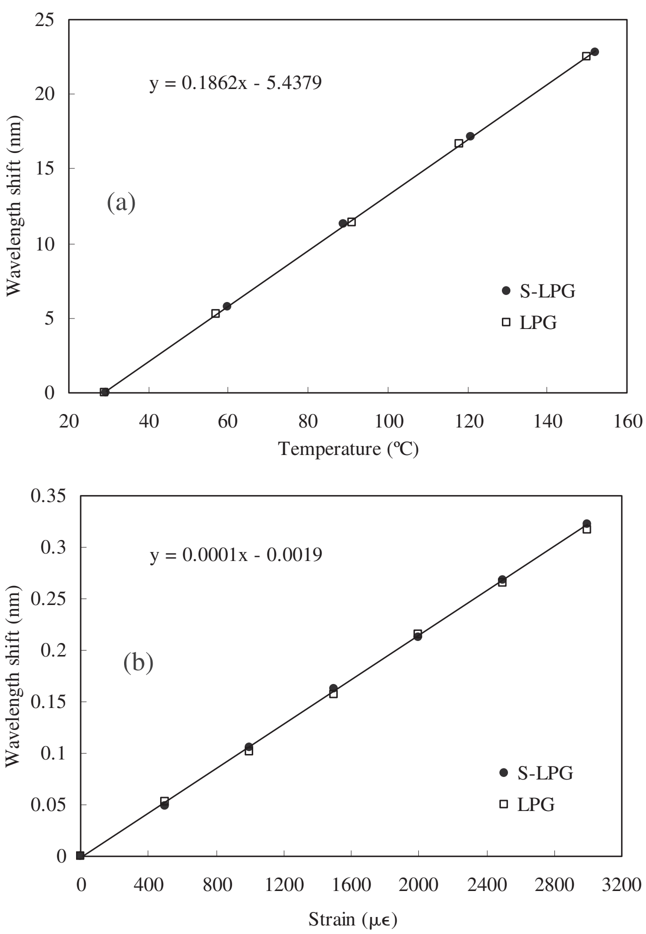

Figure 5 (a) Temperature and (b) strain responses of the S-LPG compared with those of normal LPG

5. CONCLUSIONS

Band-stop fiber-optic filters based on S-LPGs have been demonstrated. Compared with the normal LPG written in the same fiber with the same grating period and grating length, the S-LPG possesses much narrower stop bands, which can help to increase the measurement accuracy when this device is used as a sensor header, though their transmission spectra are similar and their responses to strain and temperature are the same.

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REFERENCES

1. X. Yang, X. Dong, S. Zhang, F. Lu, X. Zhou, and C. Lu, Multiwavelength erbium-doped fiber laser with 0.8nm spacing using sampled Bragg grating and photonic crystal fiber, IEEE Photon Technol Lett 17 (2005), 2538–2540.
2. V. Bhatia and A.M. Vengsakar, Optical fiber long-period grating sensors, Opt Lett 21 (1996), 692–694.
3. X.J. Gu, Wavelength-division multiplexing isolation fiber filter and light source using cascaded long-period fiber gratings, Opt Lett 23 (1998), 509–510.
4. X. Dong, X. Yang, P. Shum, and C.C. Chan, Tunable WDM filter with 0.8-nm channel spacing using a pair of long-period fiber gratings, IEEE Photon Technol Lett 17 (2005), 795–797.
5. Y.-G. Han, S.H. Kim, and S.B. Lee, Flexibly tunable multichannel filter and bandpass filter based on long-period fiber gratings, Opt Express 12 (2004), 1902–1907.
6. X. Dong, L. Su, P. Shum, Y. Chung, and C.C. Chan, Wavelength-selective all-fiber filter based on a single long-period fiber grating and a misaligned splicing point, Opt Commun 258 (2006), 159–163.
7. B.H. Lee and U.C. Paek, Multislit interpretation of cascaded fiber gratings, J Lightwave Technol 20 (2002), 500–712.
8. T. Erdogan, Fiber grating spectra, J Lightwave Technol 15 (1997), 1277–1294.