Multi-channel fiber Bragg gratings for dispersion and slope compensation

Yves Painchaud, Alain Mailloux, Hélène Chotard, Érick Pelletier, and Martin Guy
TeraXion, 20-360 Franquet St., Sainte-Foy, Québec, Canada, G1P 4N3
Phone: (418) 658-9500; Fax: (418) 658-9595; e-mail address: ypainchaud@teraxion.com

Abstract: Multi-channel FBGs for third-order dispersion compensation are reported. They cover 19 nm into 12 channels. Gratings for third-order dispersion compensation (with a dispersion varying from –810 to –860 ps/nm) and for dispersion slope compensation (with a dispersion varying from –1310 to –670 ps/nm) are presented.

OCIS codes: (060.2330) Fiber optics communications, (060.2340) Fiber optics components, (260.2030) Dispersion

1. Introduction

The management of chromatic dispersion is one of the challenges of emerging communication systems. Although chromatic dispersion helps minimizing the non-linear effects in DWDM systems, adequate management of this effect has to be performed. Dispersion Compensating Fibers (DCFs) [1] and Chirped Fiber Bragg Gratings (CFBGs) [2] are two well known solutions for compensating chromatic dispersion. DCFs are presently the preferred solution for simultaneous compensation of a large number of WDM channels. However, such a fiber is lossy and do not allow a proper compensation for all the WDM channels. Although the dispersion is properly compensated for one channel, the residual dispersion that exists at other channels can become significant and has to be compensated for after a certain propagation length.

While relatively narrowband in nature, FBGs can be made broadband by a strong increase of their length [3] or by making them multi-channel [4].

In this paper, we report on multi-channel FBGs for third-order dispersion compensation and for dispersion slope compensation.

2. Third-order dispersion compensation

Third-order dispersion compensation refers to the compensation over several WDM channels of both the second-order (D) and third-order ($dD/d\lambda$) dispersion effects. For such an operation, the compensator is required to have a different dispersion value for each of the channels. Sampled FBGs have been proposed to obtain a multi-channel operation; however the sampling function replicates a given dispersion function [5]. As a result, all the channels are identical and the resulting device cannot compensate for the dispersion slope. Single-channel non-linearly chirped FBGs have been proposed for narrowband dispersion slope compensation [6]. In order to achieve operation over a broader range, multi-channel non-linearly chirped FBGs were proposed [7]. This last approach allows a tuning of the dispersion but the spectral duty factor is limited to about 25%.

In this paper, we report results obtained with multi-channel FBGs based on superimposed gratings. Using this technique, the dispersion can be adjusted individually in each channel. The central wavelength of each channel is adjusted within ±10 pm. Typically, a FBG for the compensation of the dispersion is required to be relatively long (about 10 cm) and not ultra-strong (about 90% reflectivity). These two characteristics imply that only a modest index change (about 1×10^{-4}) is needed for a single-channel FBG which is compatible with the fabrication of multi-channel FBGs. Fig. 1 shows the reflectivity and group delay spectra of a 12-channel FBG for the third-order dispersion compensation. Also shown in Fig. 1 is the dispersion value for each of the channels in comparison with the target. The reflectivity of the grating in each channel is higher than 80%. Both the dispersion and the dispersion slope are adjusted to compensate for the dispersion accumulated over 50 km of SMF-28 fiber. The group delay was measured using a chromatic dispersion measurement instrument model Q7750 from Advantest with a modulation frequency of 250 MHz. In this demonstration, a channel spacing of 1.6 nm was chosen to emphasize on the broadband capability of the fabrication technique, although narrower channel spacing can be obtained as well. The measured dispersion values agree with the target within ±4%, and within ±2% (±15 ps/nm) for ten of the twelve channels.

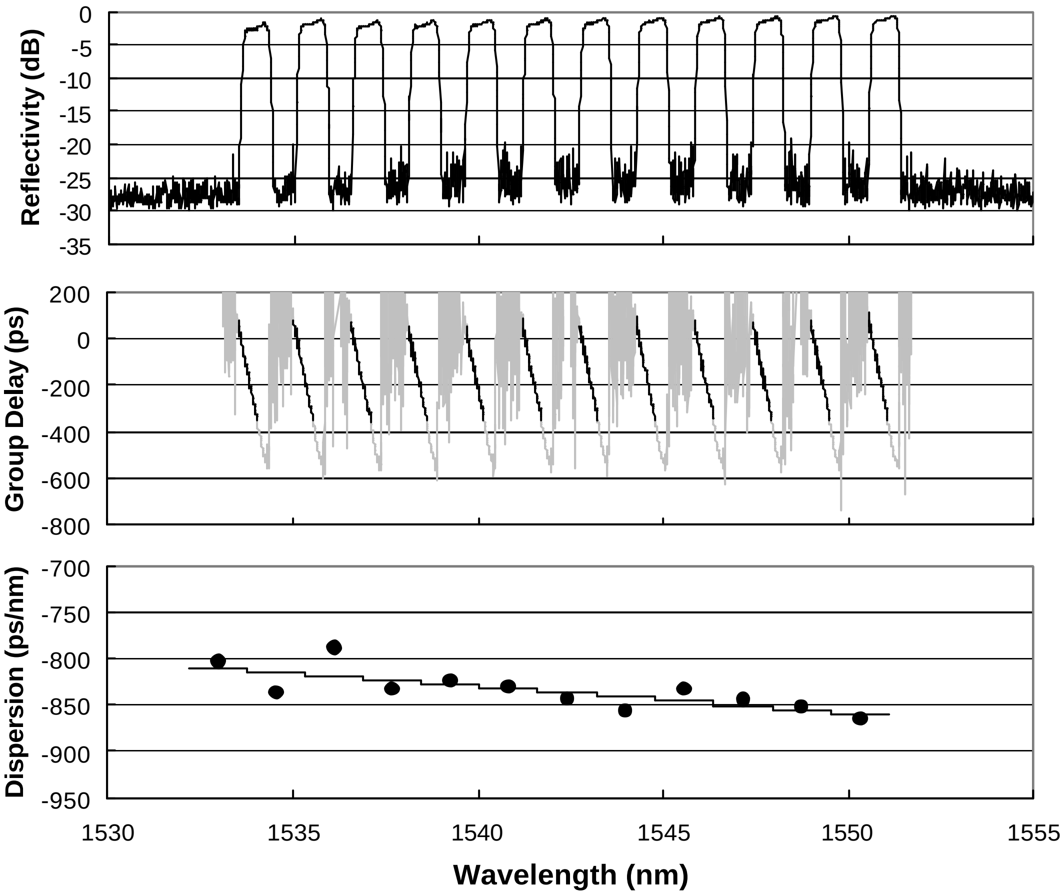

Fig. 1. Reflectivity and group delay spectra of a 12-channel third-order dispersion compensation grating (upper two graphs). The dots in the bottom graph gives the dispersion values obtained from a curve fit of the group delay while the solid line represents the target.

3. Dispersion slope compensation

The same method was used to fabricate a FBG for dispersion slope compensation. Such a device is required for trimming the residual dispersion accumulated over ultra-long distances. For example, 13.6 km of a DCF having a dispersion value of -100 ps/nm/km is required for compensating the dispersion accumulated over 80 km of SMF-28 fiber. A typical DCF compensates for approximately 60% of the SMF-28 dispersion slope so that a residual dispersion slope of 0.023 $ps/nm^2/km$ remains after the compensation [1]. A fiber link composed of 20 sections of 80 km of SMF-28 each followed by 13.6 km of DCF have a total length of 1600 km and a residual dispersion slope of 36 ps/nm^2. Fig.2 shows the reflectivity and group delay spectra of a multi-channel FBG designed to compensate for such a residual dispersion slope. Also shown in Fig. 2 is the dispersion value for each of the channels in comparison with the target. Again, the reflectivity of the grating in each channel is higher than 80%. As can be seen, a very good adjustment of the dispersion value can be obtained channel per channel.

4. Conclusion

We have demonstrated the fabrication of multi-channel FBGs in which the dispersion and the central wavelength are adjusted in each channel. The multi-channel character is achieved by superimposing many gratings on a section of an optical fiber. The adjustment of the central wavelength is precise within ±10 pm. The precision of the dispersion adjustment is close to ±2% which renders possible third-order dispersion compensation.

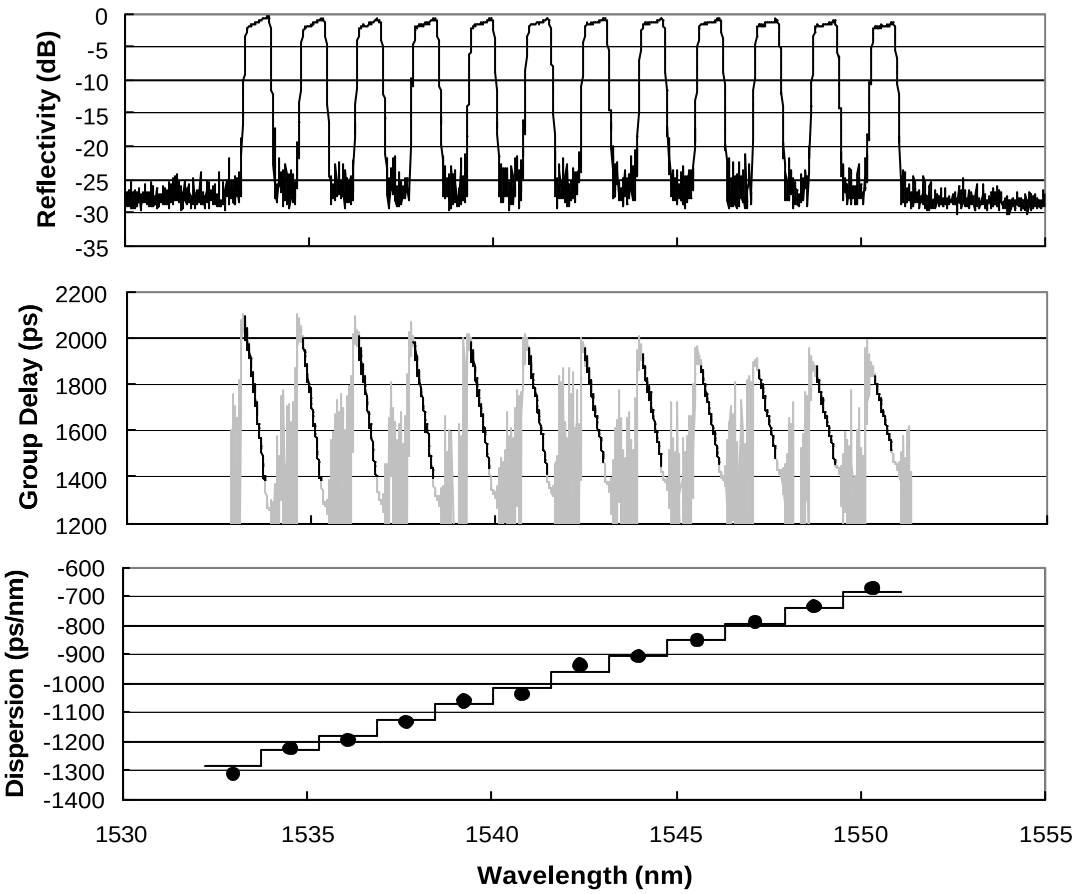

Fig. 2. Reflectivity and group delay spectra of a 12-channel dispersion slope compensation grating (upper two graphs). The dots in the bottom graph gives the dispersion values obtained from a curve fit of the group delay while the solid line represents the target.

The adjustment of the dispersion can also be done over a large range. The technique was used to demonstrate the ability to compensate for the dispersion slope with a rate of 36 ps/nm^2. More specifically, we have demonstrated that the dispersion value can be adjusted between –670 and –1310 ps/nm within the same multi-channel FBG.

The channel central wavelength can also be adjusted over a large range. As a result, channels that cover a total bandwidth of 19 nm within the same multi-channel FBG have been demonstrated.

5. References

[1] L. Grüner-Nielsen, B. Edvold, D. Magnussen, D. Peckham, A. Vengsarkar, D. Jacobsen, T. Veng, C.C. Larsen, and H. Damsgaard, “Large volume manufacturing of dispersion-compensating fibers,” *Proceedings of OFC 98,* Vol.2, pp. 24-25 (1998).

[2] F. Ouellette, “Dispersion cancellation using linearly chirped Bragg grating filters in optical waveguides,” *Opt.Lett.,* **12,** pp.847-849 (1987).

[3] M. Durkin, M. Ibsen, M.J. Cole, and R.I. Laming, “1 m long continuously-written fibre Bragg gratings for combined second- and third-order dispersion compensation,” *Electron. Lett.,* **33,** pp.1891-1893 (1997).

[4] A.V.Buryak, and D.Y.Stepanov, “Novel multi-channel grating designs,” *Proceedings of BGPP 2001,* pp. BthB3-1-3 (2001).

[5] M. Ibsen, M.K. Durkin, M.J. Cole, and R.I. Laming, “Sinc-sampled fiber Bragg gratings for identical multiple wavelength operation,” *IEEE Photon. Technol. Lett.,* **10,** pp.842-844 (1998).

[6] J.A.R.Williams, L.A.Everall, I.Bennion, “Fiber Bragg grating fabrication for dispersion slope compensation,” *IEEE Photon. Technol. Lett.,* **8,** pp.1187-1189 (1996).

[7] Y. Xie, S. Lee, Z. Pan, J.-X. Cai, A.E” Willner, V. Grubsky, D.S. Starodubov, E. Salik, and J. Feinberg, “Tunable compensation of the dispersion slope mismatch in dispersion-managed systems using a sampled nonlinearly chirped FBG,” *IEEE Photon. Technol. Lett.,* **12,** pp.1417-1419 (2000).