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On the Group Delay Characteristics of Chirped Dual Overwritten Fiber Bragg Gratings*

Cong Jun[1], Chen Xiaoming[2], Zhang Xianmin[1] **

1 *Department of Information and Electronic Engineering, Zhejiang University, Hangzhou* 310027

2 *Department of Information Science and Engineering, Ningbo Institute of Technology, Zhejiang University, Ningbo* 315104

Abstract The group delay characteristics of apodized, linearly chirped dual overwritten fiber Bragg gratings and their potential as dispersion compensators have been investigated. It is demonstrated that the group delay characteristics are affected significantly by period difference $\Delta\Lambda$ and different chirp parameter C. The results in this paper have implications on higher order fiber dispersion compensation and optical CDMA.

Keywords Dual overwritten grating; Group delay; Dispersion compensation; Third-order dispersion; Optical CDMA

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0 Introduction

Dual overwritten FBGs will be found potential applications in optic communication and sensor systems. The reflection spectra and group delay characteristics of dual overwritten fiber grating are distinguished obviously from that of single FBG because of the difference of physical structure between them. The reflection spectral characteristics of dual overwritten fiber gratings have been studied systematically in several articles[1,2].

It is well known that chirped refractive-index Bragg gratings can be used for compensating for the dispersion of optical fiber waveguides[3,4]. In this paper, the general theoretical model used for the calculation of the chirped dual overwritten grating response is described. The effects of the various period difference $\Delta\Lambda$, different chirp parameter C and gratings length L on the group delay characteristics of apodized, linearly chirped dual overwritten fiber Bragg gratings are discussed. The results show that it is possible to construct a third-order dispersion compensator by using a dual overwritten grating. The second application is to use dual overwritten grating as encoder/decoder in optical CDMA systems.

1 Theoretical model

For general apodized, chirped fiber gratings, the change in refractive index $n(z)$ as a function of distance z from the center is

$$n(z) = n_{\mathrm{eff}} + \delta n_{\mathrm{eff}}(z) \quad (1)$$

$$\delta n_{\mathrm{eff}}(z) = \overline{\delta n}_{\mathrm{eff}} A(z)\{1 + \nu\cos[\frac{2\pi}{\Lambda}z + Cz^2]\} \quad (2)$$

where n_{eff} is the effective refractive index, $\overline{\delta n}_{\mathrm{eff}}$ is the "dc" index change spatially averaged over a grating period, ν is the fringe visibility of the index change, Λ is the nominal period, $A(z)$ is the apodization profile, and C is the grating chirp rate.

Dual overwritten FBG consists of two gratings with different Bragg wavelength written in the same position in fiber. In index liner modulation by UV photoirradiation, the total index perturbation induced by dual overwritten fiber gratings can be considered as the sum of the index perturbation induced by each fiber grating. From Eq. (2), we have

$$\delta n_{1\mathrm{eff}}(z) = \overline{\delta n}_{1\mathrm{eff}} A_1(z)\{1 + \nu_1\cos[\frac{2\pi}{\Lambda_1}z + C_1z^2]\} \quad (3)$$

$$\delta n_{2\mathrm{eff}}(z) = \overline{\delta n}_{2\mathrm{eff}} A_2(z)\{1 + \nu_2\cos[\frac{2\pi}{\Lambda_2}z + C_2z^2]\} \quad (4)$$

$$\delta n_{\mathrm{eff}}(z) = \delta n_{1\mathrm{eff}}(z) + \delta n_{2\mathrm{eff}}(z) \quad (5)$$

The reflection spectral characteristics of dual overwritten fiber gratings have been studied systematically by using coupled-mode theory[1]. However, in this paper we work with the transfer matrix formalism[5], based on thin-film-filter computational techniques. This method is based on the sampling of refractive index variations within the Bragg grating period. In this way, the most relevant advantage of the proposed method is that any nonuniformities of the FBG can be modeled (chirps, phase shifts, apodization, etc) with high accuracy.

2 Numerical results

2.1 Index linear modulation

We will investigate the effects due to the difference between the parameters of two gratings. Simply, each the "dc" index change is assumed to be zero. In the models described above the "dc" index change is set to a small value while the "ac" index change is maintained at the desired value, here $\nu_1\overline{\delta n}_{1\mathrm{eff}} = \nu_2\overline{\delta n}_{2\mathrm{eff}} = 8\times10^{-4}$ by assuming a large fringe

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** Tel: 0571-87952054 Email: zhangxm@zju.edu.cn

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visibility. Assuming that $\Lambda_1 = \Lambda$, and $\Lambda_2 = \Lambda_1 + \Delta\Lambda$. The main apodization profiles, considered in the present investigation, include a Gaussian, a raised-cosine, a raised-sine, and a sine profile, etc. Here we consider the case of the sine profile, i. e. $A_1(z) = A_2(z) = \sin(\pi z/L)$.

When the period difference $\Delta\Lambda$ and grating length L satisfy

$$\Delta\Lambda L \gg \Lambda^2/\pi \tag{6}$$

The reflection spectra of the two single gratings are separate enough, the two gratings are independent of each other. The reflection spectrum of the dual overwritten grating is composed of two reflection peaks, which have their own group delay characteristics respectively determined by their own parameters, as shown in Fig. 1 and Fig. 2. By adjusting the period difference and the chirped parameter, we can realize different dispersion compensation in two separate optical wave band. It is useful to the dispersion compensation in WDM system. The parameters satisfy Eq. (6) with $\nu_1 \overline{\delta n_{1\mathrm{eff}}} = \nu_2 \overline{\delta n_{2\mathrm{eff}}} = 8\times10^{-4}$, and the chirp parameter $C_1 = C_2 = 5.23\times10^5\mathrm{m}^{-2}$, as shown in Fig. 1, and $C_1 = -C_2 = 7.58\times10^5\mathrm{m}^{-2}$, as shown in Fig. 2.

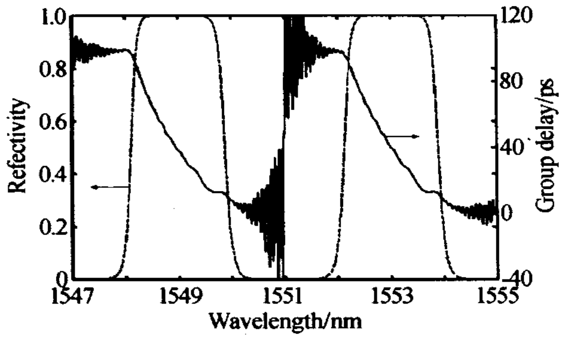
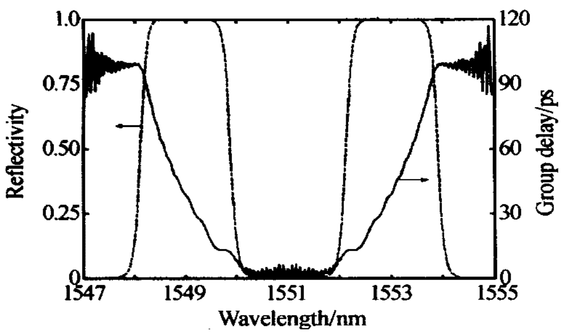


Fig. 1 Group delay characteristics of dual overwritten fiber Bragg grating with the period difference $\Delta\Lambda = 2.07$ nm



= Fig. 2 Group delay characteristics of dual overwritten fiber Bragg grating with the period difference $\Delta\Lambda = 0.7$ nm

2.2 Index nonlinear modulation

During the early stages of grating growth, it is commonly assumed that the fiber core material reacts linearly to UV photoirradiation. The illumination causes a perfect sinusoidal perturbation of the refractive index in the Ge doped fiber core. In practice the recording process is nonlinear with continued exposure of the grating resulting in saturation of the index perturbation. Considering the saturation effects, the refractive index perturbation can be express as[1]

$$\Delta n(E) = \Delta n_{\mathrm{m}}[1 - \exp(-E/E_{\mathrm{s}})] \tag{7}$$

The index increase of dual wavelength grating can be written as[1]

$$\Delta n(z) = \Delta n_{\mathrm{m}}\{1 - \exp[-\Gamma_1(1 + \nu_1\cos(\frac{2\pi z}{\Lambda_1} + C_1 z^2)) - \Gamma_2(1 + \nu_2\cos(\frac{2\pi z}{\Lambda_2} + C_2 z^2))]\} \tag{8}$$

where E is the UV fluence, Δn_{m} is the maximum index increase and E_{s} is the saturation UV fluence, Γ_1 and Γ_2 are the fluence index of each grating, respectively, which are proportional to the intensity of the UV beam.

In the case of refractive index nonlinear modulation, the reflectivity and group delay characteristics are different from the case of linear modulation. Fig. 3 and Fig. 4 show the reflection spectral and group delay characteristics with index nonlinear modulation. The parameters are as follows. The grating length $L = 1$ cm, $\nu_1 = \nu_2 = 1$, and $\Gamma_1 = \Gamma_2 = 0.83$. Here we only consider the case without

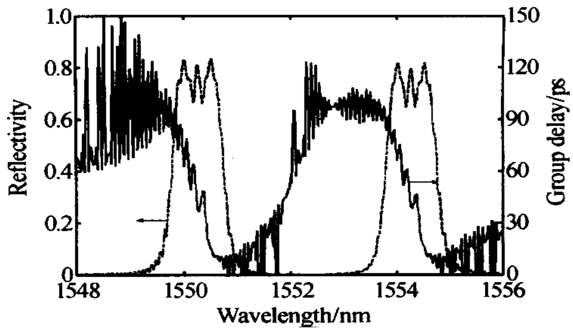


Fig. 3 Group delay characteristics of dual overwritten fiber Bragg grating with the nominal wavelength $\lambda_1 = 1550$ nm and $\lambda_2 = 1554$ nm, and the chirp parameter $C_1 = C_2 = 3.92\times10^5\mathrm{m}^{-2}$

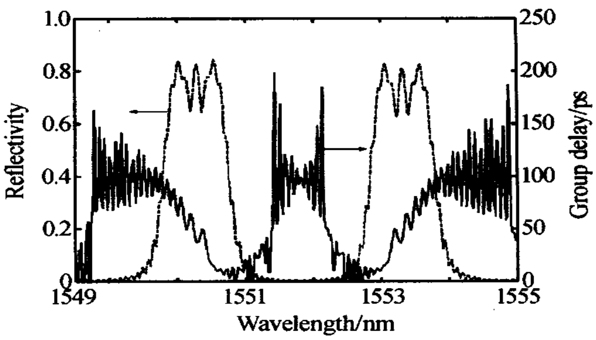


Fig. 4 Group delay characteristics of dual overwritten fiber Bragg grating with the nominal wavelength $\lambda_1 = 1550$ nm and $\lambda_2 = 1552$ nm, and the chirp parameter $C_1 = -C_2 = 3.92\times10^5\mathrm{m}^{-2}$

apodization, so the group delay curves for nonlinear recording (Fig. 3 and Fig. 4) are markedly noisier than those for linear recording (Fig. 1 and Fig. 2).

3 Discussion

From the results above, we can know that the group delay characteristics of dual overwritten fiber grating were determined by the period difference $\Delta\Lambda$, chirp parameter C, and fiber grating length L. By adjusting these parameters, we can get the group delay characteristics needed. Here we consider another case. Assuming $L = 1\text{cm}$, $\lambda_1 = 1550\text{nm}$, $\lambda_2 = 1550.8\text{nm}$, $C_1 = -6.064 \times 10^5 \text{m}^{-2}$, and $C_2 = 6.064 \times 10^5 \text{m}^{-2}$. Fig. 5 shows the group delay characteristics of that case.

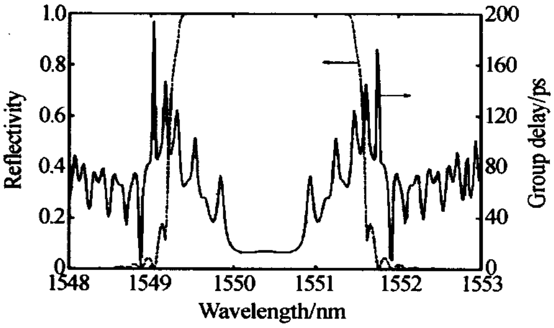


Fig. 5 Group delay characteristics of dual overwritten

By adjusting the parameters of the two gratings, different delays can be achieved in the reflection spectrum of chirped dual overwritten fiber grating. One possible application is that such dual overwritten FBGs can be further expanded as specially designed grating sequences to meet orthogonal code requirements among different channels for optical CDMA systems[6,7].

At last, we consider another application. It's well known that the chirped fiber gratings can be used for higher-order dispersion compensation[8,9]. The dispersion $D(\lambda)$ of a dispersion shifted fiber (DSF) is approximately given by

$$D(\lambda) = D_0 L (\lambda - \lambda_0) \qquad (9)$$

where D_0 is the dispersion slope or third-order dispersion (TOD), λ_0 is the zero dispersion wavelength, and L is the fiber length. A chirped fiber Bragg grating can only have a delay that changes monotonically with wavelength, therefore, the dispersion characteristic of Eq. (9) cannot be compensated with a single grating. To compensate that of Eq. (9) using fiber Bragg gratings, we must use a cascade of two non-linearly chirped gratings with different delay characteristics. However the chirped dual overwritten fiber gratings can achieve a delay that approximately changes parabolically with wavelength. Fig. 6 shows that a region (1549 ~ 1551 nm) with approximately parabolic group delay characteristics is achieved in the reflection spectra of dual grating. Fig. 7 shows the group delay characteristics of that region which can be used to compensate the TOD of a 400-km-long dispersion shifted fiber. The dotted line corresponds to a parabolic fit, which is the ideal case.

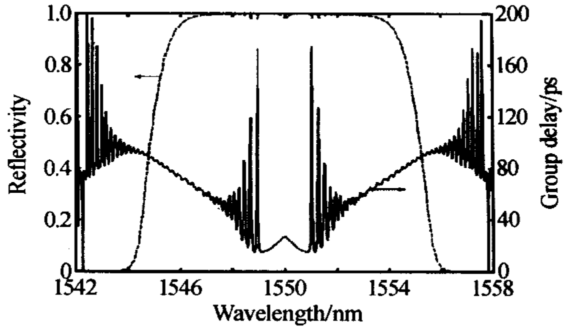


Fig. 6 Group delay characteristics of dual overwritten fiber Bragg grating with $\lambda_1 = 1548$ nm, $\lambda_2 = 1552$ nm and the chirp parameter $C_1 = -2.092 \times 10^6 \text{m}^{-2}$, $C_2 = 2.092 \times 10^6 \text{m}^{-2}$

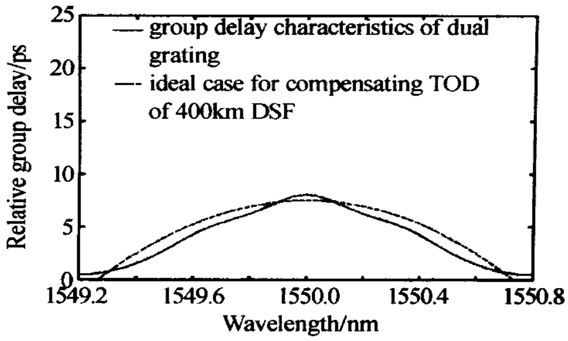


Fig. 7 The group delay characteristics of the TOD compensation with dual grating

4 Conclusions

We have analyzed the group delay characteristics of dual overwritten FBGs based on transfer matrix formalism. The group delay characteristics of dual overwritten fiber gratings are distinguished obviously from that of single FBGs because of the difference of physical structure between them. Because of the different characteristics, dual overwritten fiber grating will be found potential applications in third-order dispersion compensation and optical CDMA. This device has the potential to play an important role in the future high bit rate optical transmission systems. In addition, they can also achieve different dispersion compensation in different optical wave band by adjusting the nominal period and chirped parameter of the dual overwritten fiber grating.

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啁啾双光纤光栅群时延特性

丛 军[1] 陈晓明[2] 章献民[1]
(1 浙江大学信息与电子工程学系 ,杭州 310027)
(2 浙江大学宁波理工学院信息科学与工程系 ,宁波 315104)
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摘 要 研究了变迹线性啁啾双光纤光栅的群时延特性及其在高次色散补偿中的应用 . 分析表明 ,群时延特性与周期差 $\Delta\Lambda$ 和不同的啁啾参量 C 有很大的关系 . 研究结果表明啁啾双光纤光栅在高次色散补偿和光纤 CDMA 中有应用价值 .
关键词 双光纤光栅 ;群时延 ;色散补偿 ;高次色散 ;光 CDMA

Cong Jun was born in 1977 ,in Shandong , China. He received his B. S. degree and M. S. degree from Department of Information and Electronic Engineering , Zhejiang University , in July 2000 and March 2003 , respectively. His researches are interested in the field of fiber sensors and fiber gratings.